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The Three Hundred and Eighty-ninth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, February 26th, 1903—Mr. JAMES SWINBURNE, President, in the chair.

The minutes of the Ordinary General Meeting of February 12th were, by permission of the meeting, taken as read, and signed by the President.

The names of new candidates for election into the Institution were also taken as read, and it was ordered that these names should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

From the class of Associate Members to that of Members—

Sydney Evershed.
Edgar Llewellyn Ingram.
W. F. Stuart-Menteth.
Laurence Maxwell Waterhouse.

From the class of Associates to that of Members—

Frederick William Topping.

From the class of Associates to that of Associate Members—

George Ernest Etlinger.
Archibald Ernest Grant.
Arthur Frederick Harris.
Leopold J. Harris.
Arnold Grant Livesay.
William Marsh.
Francis Samuel Miller.
Alexander Houston Weddell.

From the class of Students to that of Associates—

Samuel Blackley.
Sydney Elliott Glendenning.
Mahmoud Samy.

Messrs. W. R. T. Cottrell and W. Nairn were appointed scrutineers of the ballot for new members.

Donations were announced as having been received since the last meeting to the *Library* from the Maschinenfabrik Oerlikon, and the Relatives of the late A. T. Weightman; to the *Building Fund* from

Messrs. A. Eden, F. Heppenstall, H. W. Lee, A. P. Pyne, R. C. Quin, D. C. Wardlaw, L. Wilson; and to the *Benevolent Fund* from J. W. Fletcher, J. G. Wilson, and J. H. Woolliscroft, to whom the thanks of the meeting were duly accorded.

The PRESIDENT: Mr. W. R. Cooper, who has been the Institution's representative on the Committee of *Science Abstracts*, has been elected Secretary of the Physical Society, and therefore he can no longer represent this Institution. Mr. Kingsbury has kindly consented to take his place, but the Council particularly instructed me to mention this matter to the meeting, because we feel that the Institution is very much indebted to Mr. Cooper for the immense amount of hard work he has done as editor in past days, and the work he has most recently done as the most active member of the Committee.

At the last meeting I reminded members of the Institution that the Council would be glad to receive any suggestions of names for the candidature of the new Council. As I then explained, the Council do not bind themselves in any way to nominate people so recommended, but they will be very glad of any names suggested by members, and they will be carefully considered.

I will now ask Mr. J. Stöttner to read the paper in his name on the Nernst Lamp.

THE NERNST LAMP.

By J. STÖTTNER, Member.

Few inventions in electrical science have created greater expectations, excitement, and speculation than the Nernst Lamp, and with few have there been such immense difficulties in obtaining practical and satisfactory results.

From the time of the earliest application of the Edison glow-lamp attempts were made, first, to discover a substitute for the carbon filament; secondly, to avoid the necessity of evacuating and sealing the globe; *and thirdly*, in case of the filament giving out, to accomplish its exchange without at the same time throwing away the body of the lamp itself.

In 1877 Jablochkoff took out a patent for a lamp in which the illuminating body consisted of kaolin and similar refractory earths, which become conductors of electric current as soon as heated to a certain temperature.

Partly on account of the very low efficiency, but more particularly by reason of the necessity for very high-tension currents, this invention —in common with all other attempts—proved a failure, until Professor Walther Nernst came to the front with his lamp in the year 1898.

I have lately visited the extensive lamp works of the Allgemeine Elektricitäts-Gesellschaft, and will endeavour to make you acquainted with the development of the Nernst lamp manufactured there from its earliest stage up to its present design, for which purpose the A.E.G. has been kind enough to supply me with original samples of the lamp

in its various stages of development and design. The filaments of all these lamps are made of rare earths, principally of zirconia.

The earlier types of Nernst lamps had no automatic heating arrangement, and the filament or glower, as our cousins in America call it, had to be heated to the temperature required (on an average about 700° C.) to make it a conductor, by means of a spirit lamp or match.

The very first lamp brought out was type No. 1 (Plate I.) with a straight filament, the compensating resistance (or bolstering resistance as it is termed on the Continent) of which, consisting of a fine platinum wire, was arranged in parallel with the filament at a distance of about ¼ in.

In type No. 1A (Plate I.) the filament was bent in a similar manner to that of the first Edison bamboo carbon incandescent lamp, and was in the shape of a horseshoe. The burner of this lamp could be exchanged.

The bulb was open in order to facilitate artificial heating of the filament, as mentioned before. The bolstering resistance, to which I shall refer again later, consisted of fine platinum wire wound round two small porcelain tubes, and was exposed to the air to obtain a better cooling effect.

The filament in type No. 2 (Plate I.) was exactly the same as in No. 1A, but the bolstering resistance was wound on one small porcelain tube only, and partly covered with kaolin.

In type No. 3 (Plate I.) the resistance consisted of thin iron wire wound on a very small kaolin tube, which was sealed and enclosed in a glass tube. This tube was evacuated and afterwards filled with hydrogen gas. All these models, however, proved unsatisfactory, and platinum wire was again resorted to as a bolstering resistance, as type No. 4 (Plate I.) shows.

In this lamp the large loop is the resistance, which was prepared in almost exactly the same manner as the heater of the present day, a very fine platinum wire being wound in a spiral on a thin kaolin tube and then steeped in a solution containing kaolin. The small loop is the filament. It will be noticed that in this lamp filament and resistance are fixed for the first time on a porcelain base. This shape of resistance was in use for a considerable time and will be seen again in the later types.

The trouble of lighting the lamps by means of a spirit lamp or match, however, prevented their being brought into general use. They were exhibited for the first time in public in conjunction with some automatically-heated lamps at the Paris Exhibition of 1900, where the patentees, the Allgemeine Elektricitäts-Gesellschaft, of Berlin, had a magnificent pavilion lighted entirely by Nernst lamps. At this time the difficulties had by no means been overcome, but seemed rather only to have commenced, and it was found absolutely necessary to effect the heating of the filament automatically in order to bring the lamp into practical use.

In type No. 5 (Plate I.) the automatic heater will be observed for the first time. The filament in this type was again a straight rod, placed horizontally to the base of the lamp. The thick porcelain tube next to it contained the heating wire, and the smaller tube the bolstering resistance. Both filament and bolstering resistance in this lamp could be exchanged. The automatic cut-out was embedded in the socket. It will be observed that the magnet had great masses of iron and a

heavy armature, in consequence of which a great deal of energy was required to actuate it.

In type No. 6 (Plate I.) we see for the first time a heater in the form of a coil, in the centre of which the filament is placed. The heating coil was prepared in a similar manner to that in type No. 4, but mounted together with the filament on a somewhat larger base, and could be easily exchanged. The bolstering resistance was the same as in type No. 3 and could be exchanged, but was firmly fixed to the socket. The magnet was identical with that of type No. 5, and the glass bulb similar to that of an ordinary incandescent lamp.

Type No. 7 (Plate I.) is very similar to No. 6. This lamp was designed for 220 volts. The filament could not be arranged in a horizontal position on account of its length, and therefore both filament and heater were mounted vertically to the base.

A great improvement is shown in type No. 8 (Plate I.). Here for the first time will be observed in the bolstering resistance spirals of thin iron wire suspended free of the carrier.

Type No. 9 (Plate II.) was a departure from the usual practice, in which a loop filament was again used and a magnetic cut-out placed alongside of the bolstering resistance instead of being embedded in the socket.

Up to this time the lamps had been manufactured only in small numbers, but types Nos. 10, 11, 12 (Plate II.) and 13 (Plate III.) were now designed and for the first time produced in considerable quantities. These lamps show two distinct forms, the "A" type with large body and globe, and the "B" type with small round globe and body so arranged that it could be used in an ordinary Edison screw lamp socket.

The "B" lamps, types 10 and 11 were manufactured for an energy consumption of 40 and 80 watts and potentials of 110 and 220 volts respectively. The bolstering resistance in these types again consisted of platinum wire as in type No. 4. As on account of their small size it was impossible to combine these filaments with a modern iron resistance they were all arranged in a horizontal position. The heating spirals were mounted firmly on the porcelain baseplate, which could be easily exchanged. In these lamps the magnet of the automatic cut-out received its final shape, being marked by very small masses of iron and a very light spring, and in consequence thereof by a very small loss of energy. The "A" lamps were for higher currents up to 1 ampere, and had to be separately connected in a similar manner to that in which an arc lamp is connected.

Types 12 and 13 were designed for an energy consumption of 100 and 200 watts with a corresponding lighting capacity of 65 and 130 standard candle-power respectively. In this type the burner, as well as the bolstering resistance, could be independently exchanged. These lamps were made for 110 and 220 volts. As opposed to the "B" lamp, the filament and the heating coil were arranged in a vertical position. The design of the magnets of the automatic cut-outs was exactly the same as that in the "B" lamps. The metal cap covering the resistance was provided with ventilating slots, so that the bolstering resistance was cooled by the circulation of air.

PLATE I.
(Showing Nernst Lamp, Types 1-8.)

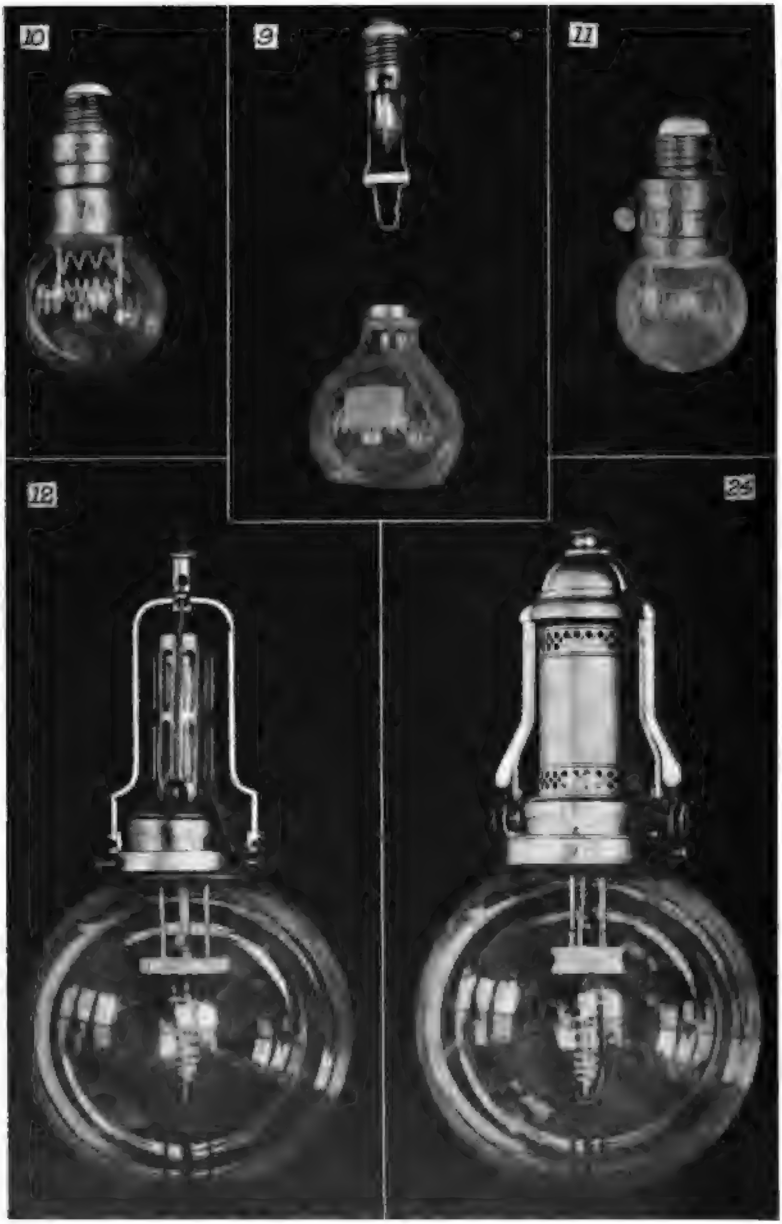


PLATE II.

(Showing Nernst Lamp, Types 9–12, and 24.)

Plate III.

(Showing Nernst Lamp, Types 13 and 25.)

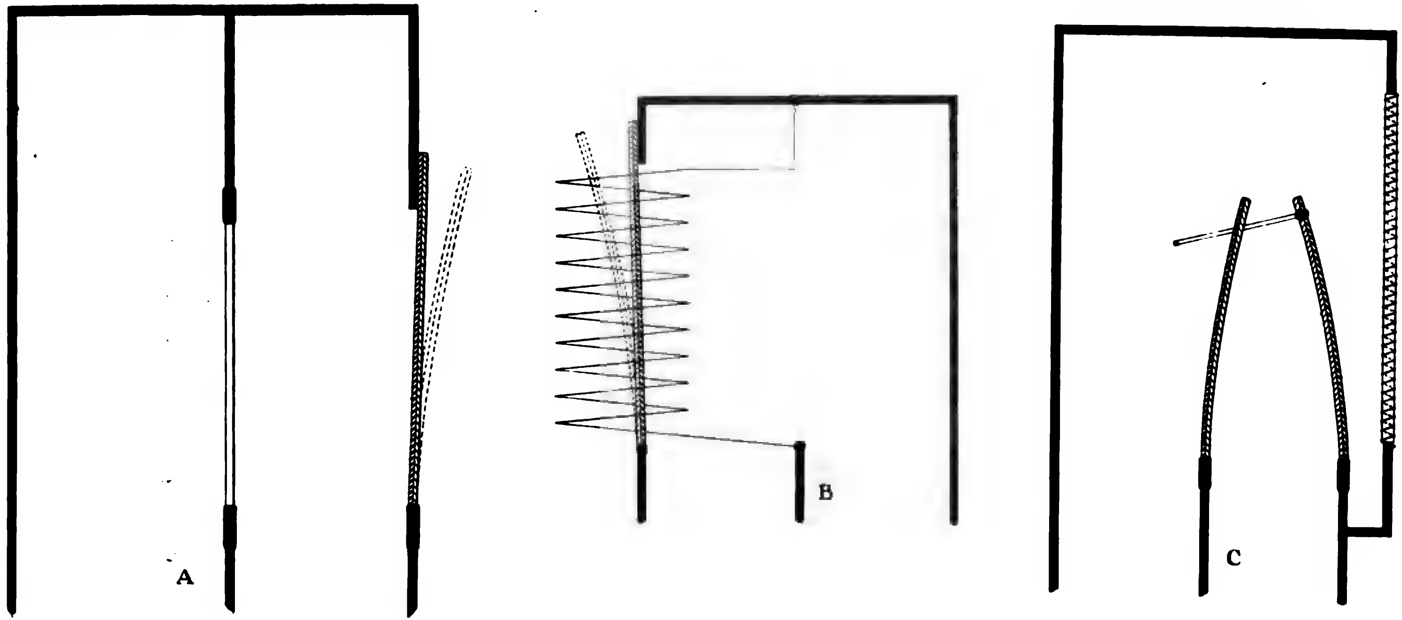


PLATE IV.

Types Nos. 14, 15, 16, 17 and 17A show the development of the Nernst lamp as a candle lamp for chandeliers, etc. These lamps do not deviate materially from those described up to now, but correspond with the ordinary lamps in each successive stage of development.

In Nos. 18, 19 and 20, the gradual reduction of the iron masses in the magnet will be noticed. The first magnet weighs about three times as much as those in use at the present day.

Nos. 21, 22 and 23 (Plate III.) show experiments in disconnecting the heater by other means than that of an electromagnetic cut-out.

Sketches A, B and C (Plate IV.) show the corresponding diagrams of current in these devices. The springs of compound metal bend to one side as soon as heated. These inventions, however, did not come into practical use and, indeed, never left the laboratory. I merely mention them to show that all kinds of researches were made with the object of improving the details of Nernst lamps.

Nos. 24 (Plate II.) and 25 (Plate III.) show the latest patterns of Nernst lamps, as now in use by the million.

No. 24 is the A type lamp. The burners are manufactured for 1 ampere up to 250 volts, and for ½ ampere, only, from 200 up to 250 volts. The metal hood is furnished with metal combs of thin sheet copper in the inner cover, for the purpose of cooling the bolstering resistance. Between this inner tube and the outer mantle are a number of tubes for ventilation purposes and to facilitate the radiation of heat.

The replacing and fixing of burners is a very simple manipulation, and can be effected by any unskilled person.

For customers who have A lamps of the old type we have designed special adapters, so that the new burners can be used on such lamps.

No. 25 (Plate III.) is the latest B type lamp, which is manufactured for ¼ and ½ ampere up to 150 volts, and for ¼ ampere up to 250 volts.

The replacement, etc., of burners is quite as simple as in the case of the A type lamp.

Nos. 26 to 36 are various bolstering resistances, all made of iron wire, sealed in glass globes which have been evacuated and afterwards filled with hydrogen. Iron wire is used on account of its high temperature correction, which makes it particularly suitable, as, for instance, should the current increase 5 per cent. the resistance of the iron wire increases about 75 per cent., thus preventing the destruction of the filament. The increase of resistance in the iron wire is not proportionate throughout, and it is therefore necessary that the sectional area should be chosen with a view to heating the wire to a critical temperature by the current with which the lamp is intended to burn, in order to arrive at the above-mentioned result, i.e., the balancing of current by resistance.

Nos. 37 and 38 show filaments which have burned 1,400 and 1,600 hours respectively. Unfortunately No. 37 is broken, but from No. 38 it can be easily seen that the filament has become crystallised. It is also black throughout; this discoloration starts at the negative pole and gradually extends over the whole filament. The precise cause of this crystallisation and blackening is not at present known, but we presume that it is due to electrolysis.

As to the efficiency and life of the Nernst lamp, I refer to the table of tests made at the Physikalische Technische Reichsanstalt at Charlottenburg.

A number of lamps have been under test at the Electrical Testing and Standardising Institution at Faraday House, London, since the middle of December. The results, however, are still outstanding.

A great many errors in the treatment of Nernst lamps are committed, in consequence whereof numerous complaints of short life, etc., are lodged with the suppliers; but if instructions are carefully followed a life of about 300 to 400 hours—as practical results show—may be expected. One great mistake generally made is that the current is sent through the lamps in the opposite direction to that intended, particularly in the "B" type lamp. Another mistake is to overrun the lamps, as the surplus current is then taken up by the bolstering resistance and practically the light is not in the least increased.

On the Continent the screw holder is in almost universal use, and the standard rule is to make the centre contact minus; it is therefore immaterial how frequently the lamps are taken out of their holders, as they always come back to their proper position. With bayonet lamps it is different: the poles can be easily changed by inserting the lamps the wrong way, and to prevent this the A.E.G. have designed a tool to cut out a slot, and have provided the porcelain socket of the lamp with a third pin, so that it is impossible to get the lamps into the holders the wrong way.

To determine the polarity on bayonet sockets special pole-finders are supplied, the negative pole being invariably indicated by the red appearance of the solution.

I have studied the principles and designs of the Nernst lamps manufactured in the United States, and think that we here in the Old World may pride ourselves on being at least as up-to-date as our American cousins.

Mr. Drake. Mr. B. M. DRAKE: We are indebted to Mr. Stöttner for kindly giving us the history of the evolution of the Nernst Lamp, as worked out by the Allgemeine Elektricitäts-Gesellschaft, of Berlin, and it may be of interest to compare what has been going on in this country in connection with the same problem. As you may know, when this invention was first brought to public notice, attempts were made at a meeting at Berlin of the holders of all the patents of Nernst for the world to arrange for an interchange of experience by which the lamp might be brought to perfection in less time than would be possible if each worked on his own account. At that meeting, which Mr. Swinburne and I attended on behalf of the Nernst Electric Light Company, there were present Mr. Westinghouse, the Allgemeine Elektricitäts-Gesellschaft, and Messrs. Ganz. Two days were spent in discussing the invention, which was regarded as marking a new era. There was a serious discussion as to the result on the electrical industry when the lamp should make its appearance. One influential member said there was no doubt that if these lamps were put upon the market indiscriminately the supply companies' business throughout the world

would be affected to a serious extent: the companies would suddenly find that their output was halved, with the result that it would be impossible for them to pay dividends for the year. It was further stated that it would be impossible for the wiring contractors, however numerous they might be, to wire the additional houses which would at once rush for the electric light, owing to the fact that the cost of lighting would be halved. All sorts of methods were suggested as to how the lamp should be put upon the market gradually, so as not to upset the electrical industry. These hours of discussion, however, were somewhat wasted, for providence looked after the electrical industry. As soon as we had finished our discussion, we all went home and discovered that none of us could make the lamp at all. Unfortunately, owing to international jealousy, we were unable to come to any arrangement by which we could arrange an interchange of improvements, and the result was that each tried to work out the lamp for himself. There are on the table specimens showing the progress of the Nernst lamp as we designed it in England. Unfortunately we had not the unbounded resources of the Allgemeine Elektricitäts-Gesellschaft, and we were blessed with a boisterous set of shareholders, who would not leave us alone, besides which we had to manufacture out of England. Had it not been for these drawbacks I think we should have put our lamp on the market as soon as, if not sooner than, the Allgemeine Elektricitäts-Gesellschaft. Some of the results which we were able to produce are shown in the curves exhibited. These are the mean results of a number of tests which were made; and you will see from the Curve Fig. A that we were able to produce lamps which Mr. Drake.

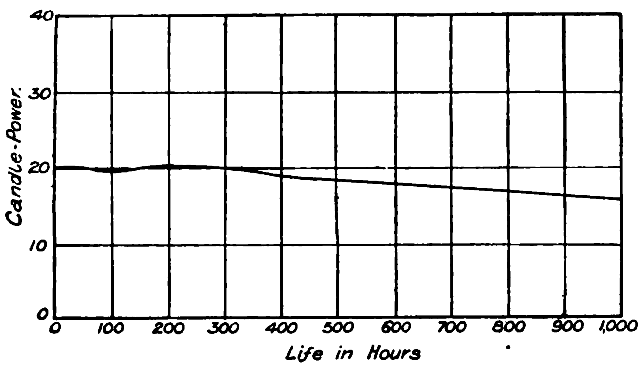


FIG. A.

started at 20 candle-power, and after 800 hours had only dropped to 16·5. The tests were very carefully taken, and will compare favourably with the results obtained by any carbon lamp which has ever been made: the average watts being 2·7 per candle throughout the whole period. The next diagram (Fig. B) shows the drop in candle-power of large lamps of 200 volts, starting at 130 candle-power and ending at about 80, with a mean efficiency of 2·3 watts in 700 hours.

Mr. Drake.

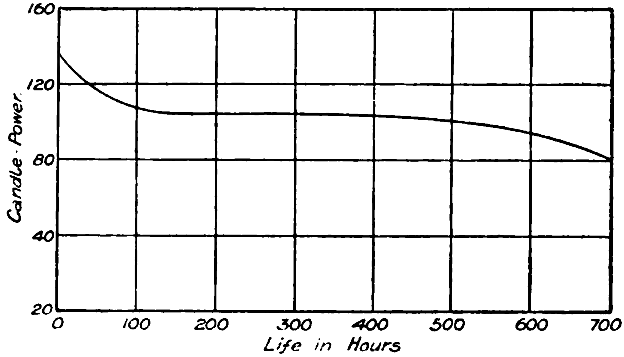


FIG. B.

the Curve Fig. C shows the rapid way in which the volts absorbed by the resistance increase with the smallest increase of current. The result is that when these series resistances are used with Nernst lamps you get a more regular candle-power with variations of voltage than with the carbon lamp. The Curve Fig. D shows the percentage variation of candle-power of the carbon lamp and the Nernst lamp, with different voltages. It will be seen from this that in the Nernst lamp the candle-power does not increase to anything like the same extent as in the carbon lamp. The carbon lamp, with a rise from 100 to 115 volts, has increased in candle-power in a ratio of 100 to 230, whereas the Nernst lamp under the same increase of pressure has only increased to 130. The iron resistance may be looked upon as one of the turning points in the Nernst lamp, and it will be used to advantage in series with the ordinary carbon lamp on traction circuits where the voltage is not very regular. In Mr. Stöttner's paper there are one or two points, probably slips, to which perhaps he will not mind my referring. Near the top of page 521 he talks of the resistance being arranged in parallel with the filament; I think he means in series.

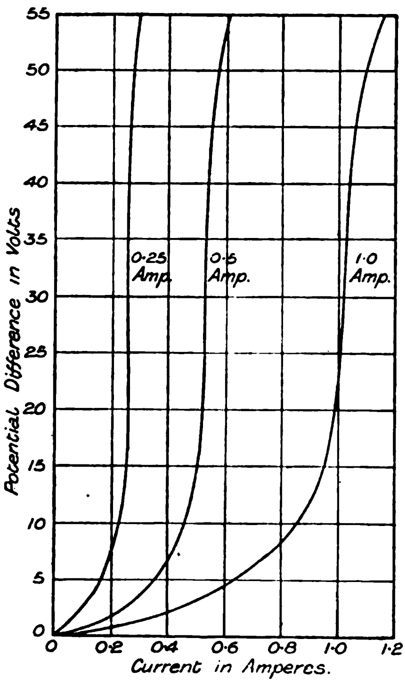


FIG. C.

Mr. STÖTTNER: As a matter of fact the resistance and filament are arranged in parallel, but electrically, of course, they are connected in series. Mr. Stöttner.

Mr. DRAKE: The next point is with regard to the claim of the Allgemeine Elektricitäts-Gesellschaft to be the first to show an automatic lamp. Mr. Swinburne will bear me out that the lamp originally shown at the Society of Arts, which is on the table, is automatic, the heating hood being lifted by a powerful magnet away from the glower. Also automatic lamps made by Ganz were shown in 1899, at the Royal Society. The Ganz lamps are also on the table for the inspection of members who would like to see them. The lamps which are alight now are some of the products of the Nernst Company. I would ask Mr. Stöttner to look at one of them with duplex glowers, because the Allgemeine Elektricitäts-Gesellschaft might do well to adopt it. We have not seen any of their make arranged in this way, and for street lighting they are very suitable because a single glower hardly gives enough light for street purposes, whereas the two just suffice. The Westinghouse Company have not up to the present produced a continuous-current lamp, Mr. Westinghouse having concentrated his attention on the alternating lamps, and, curiously enough, we found the alternating a much more difficult problem than the continuous. The Westinghouse lamps, which are also on the table, consist of a large number of small glowers; I presume he found difficulty in baking the large glowers, which is a difficult problem, and required a considerable time to solve. Mr. Westinghouse fuses the conductors into the ends of his glowers in a way which is different from that adopted by others, which is apparently better for alternating glowers. Messrs. Ganz started very energetically on the Nernst lamp, and the specimens shown on the table are very creditable examples, considering the time at which they were made. But as soon as they found the enormous outlay which would be necessary in order to bring the Nernst lamp into a practical state, they apparently got frightened and Mr. Drake.

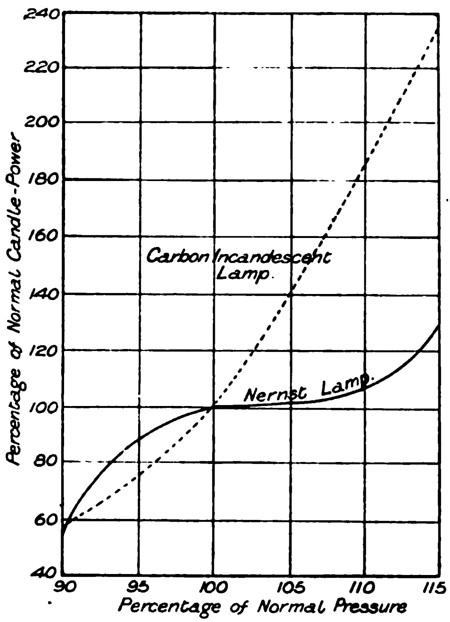


FIG. D.

Mr. Drake. left it alone altogether. We, for commercial and company reasons, have made arrangements with the Allgemeine to manufacture for our districts, and therefore the Allgemeine must be given the full credit for being the first in the world to put the Nernst electric lamp on the market in a condition in which it will meet commercial requirements.

Mr. Hammond. Mr. R. HAMMOND: I was hoping that the general body of the members would take the opportunity presented to them of having these leading experts on the Nernst lamp in the same room with them, to do a little heckling. And I am surprised at the backwardness of those who, I am sure, have so many questions to ask. Possibly, however, they will come on a little later in the evening. With regard to my attitude towards the lamp—and I think possibly it is the attitude of most of us—I feel that the ideas which were prevalent originally that the introduction of a lamp of very much higher efficiency would greatly damage our industry, are absolutely chimerical. The more cheaply we can utilise the energy which we produce, the more cheaply we can give light, and the more important will our industry grow. I had the pleasure of visiting the Buffalo Exhibition, and I was very much struck with the splendid exhibit of George Westinghouse; I spent more time in that portion of the exhibition than in any other portion, and I came back to England feeling that there was no reason why we should not start in this country street-lighting by means of Nernst lamps. Now, I am much interested, as I am sure you all must be, to hear from Mr. Stöttner that the whole question of the efficiency and life of the lamp has been settled by the tests made at the Physikalische Technische Reichsanstalt of Charlottenburg. You tell that to a town councillor, and unless he can get his friends to vote him a sufficient sum to go and visit these works himself, he wants the efficiency demonstrated on the spot. I therefore undertook for my friends and paymasters at Hackney to carry out a mile of street lighting on the Nernst system; and I was anxious to do so, not that I disregarded the wonderful results that were achieved by the Physikalische Technische Reichsanstalt of Charlottenburg, but because I felt that if the Nernst lamp was going to supersede the old-fashioned lighting which prevails in the streets of the United Kingdom, it would do so after practical results in the streets, rather than in the laboratory of the Physikalische Technische Reichsanstalt, that very excellent institution at Charlottenburg. Now, we have got a mile of street lighted, and in due course I was called upon, in conjunction with the resident electrical engineer, Mr. L. L. Robinson, to give a report as to the extension of the lighting to the whole of the 125 miles of streets in Hackney. Well, of course, as a consulting engineer always anxious to extend the scope of one's work, I was naturally tempted to say, Go in and light the whole mileage. But with due regard to a character which it is so difficult in these days to keep, I felt that it would be well that I should lay before the councillors of Hackney some actual results. And I, knowing their attitude, did not drown them with those achieved by the Physikalische Technische Reichsanstalt of Charlottenburg. I had to tell them how much per annum each lamp was likely to cost them on the basis of the life—or want of life, because you cannot tell the length of life until it

Mr. Hammond.

is dead—of those that had already been put up. You see, gentlemen, how far removed from science one sometimes has to be. And finally I laid before them this report. It is not all Physikalische Technische Reichsanstalt; there are one or two other things in it, and I shall have very much pleasure in presenting it to the Institution, which will be even a greater pleasure than reading it all through to you to-night. So that if it be deemed worthy, or if any portion of it be deemed worthy by the Editing Committee to constitute a sort of supplement to the scientific contribution that has been so ably made to-night, it is at the disposal of that Committee. But what I found was this:—First, that of these lamps, which were placed roughly about 42, 43, 45 yards apart, 40 lamps going to the mile, the first one finished his life in 130 hours. The cause of this failure was failure of flex connected to the glower. Now I am sure you will all agree with me that having a gentleman before us who is so well acquainted with the reason of flexes failing, he will be able to give us some idea of how we shall be able to arrange that in future the flexes connected with the glower do not fail. I may say that by the commercial arrangement which has been referred to by Mr. Drake, all the lamps were obtained from the Electrical Company, and it is therefore for Mr. Stöttner to tell us why in No. 1 lamp, which we thought was going to last so efficiently for 800 hours, the flex failed in 130 hours. We had, of course, to fix another lamp in its place, and the second lamp, up to the time of the making of these tests, lasted 930 hours, and he is going on lasting. With regard to the No. 2 lamp in the street, it was going merrily on after 542 hours. No. 3 lamp had to have a good deal of attention paid to it. We had men carefully patrolling this mile the whole time, so as to be able to get accurate results. The first lamp fixed on No. 3 post disappeared in 34 hours because there was a fracture of the glower at bottom contact; and that is the constant fault we have discovered, at all events at Hackney. This report, I may say, is dated February 2nd of this year. The second lamp fixed on No. 3 post gave a life of 96 hours, and in that, again, there was fracture of glower at bottom contact. The third lamp put in there lasted 453 hours, and died from failure of heating-coil due to faulty action of auto-cutout. We put in a fourth, and that disappeared in 150 hours; he went back to the old complaint, and, like his grandfather and his greatgrandfather before him, he died from fracture of glower at bottom contact. And the fifth lamp took up the running, and at the time of the test was 241 hours old. I am not going to weary you by reading the history of the whole of them, but the awkward thing is this, that the lives vary considerably. It reminds you of a chapter in Genesis, because some of them lived to such an advanced age; they vary from 1,070 hours and still young, to 15 hours and dead and gone. And the 15-hour one died from failure of the heating coil. We put another one in his place, who only attained a life of 30 hours, and he died from failure of the heating-coil. Well now, these figures, which I think you may take as absolutely reliable, can be summarised as follows. The total number of burners tested to full life was 67. The total burner hours, including only such burners as failed, was 20,499; the average life of the burners, that is to say the

Mr. Hammond.

dead ones (as we cannot get their average lives till they die), was 305 hours. Taking that as the basis of the life, I was compelled to get these results out in advising as to whether I could conscientiously recommend the Vestry to permit me to light the whole 125 miles of streets by this means. We found that these lamps gave their 80 candle-power pretty consistently with the half an ampere on a 240-volt circuit. I will take the working cost of 3,940 hours per annum, debiting the current at 1¾d.—as a matter of fact it was 1·7d.—debiting them with renewals on the basis of the life shown by these experiments, 11·5 burners and one resistance and one globe, sundry stores and labour. We thus get a certain net cost of working. The lamps then have to be debited with the interest on the repayment of capital on the basis of a ten years' loan at 3½ per cent. plus 8½ per cent., equals 12 per cent., a total sum of £5 17s. 9d. per annum. Well now, in this country the town councillors [of course not the electrical engineers (nothing in the way of electricity is too dear to them), who may consider that £5 17s. 9d. would be a very proper expenditure per lamp for the sake of having the Nernst lamp] think that that figure does not compare favourably with the price which would hold at all events if the lamps lasted as long as they do at Charlottenburg. I think we may ask Mr. Stöttner to help us in his reply to explain the causes of these failures, because, speaking for myself as representing Hackney, I should be only too delighted if these failures did not occur, and if the whole of those 125 miles of streets were lighted with that lamp. And I think that what applies to Hackney applies also through the country. We cannot do with a lamp that has not a uniform life. In the early days of the incandescent lamp, as we recollect, and our President will remember one or two episodes with regard to it, the difficulty was not that of making the lamp—our President made them in large quantities —but the difficulty was that of getting them uniform. If you attempt to put in lamps for street lighting some of which last 15 hours, and some of which last 1,000 hours, it puzzles even a consulting engineer, electrical as he may be, or otherwise, to determine the proper number of renewals which he has to provide for; because you cannot have street lighting with certain lamps out and certain lamps in. The disinclination to push the Nernst lamp throughout the country is, I think, largely due to its not being a truth-teller; he does not always do what his brother did yesterday. If we can get all the members of the family to live the same life, even if it is not 800 hours, but 790, or 665, we shall have attained very much nearer to its adoption than we have got to-day.

Professor Ayrton.

Professor W. E. AYRTON, F.R.S.: I will only say one word, as it is getting very late. I want to ask one question. Mr. Hammond has dealt in a very facetious way with the attempt to light a street in Hackney with the Nernst lamp; but the point I wish to deal with is the one which Mr. Hammond has passed over so easily. He has only dealt with failure arising from mechanical causes. No doubt those are very serious for any practical system of lighting, but with improved manufacture those failures can be overcome. But what I want to deal with is the point which he passed over, namely, that these lamps do

give the 80-candle-power light during the whole of their life. Now, my experience has been the opposite. It is a small experience, I grant as far as lamps that I have used myself is concerned, but it is not a small one if one looks at the Nernst lamps in shops and various other places. And I would like to ask one of the numerous experts whom we have the pleasure of seeing here to-night on the subject of this Nernst lamp, why the practical Nernst lamp does not follow any such curve as shown in those diagrams. If the English Company were able some time ago, as I understood Mr. Drake to say, to make Nernst lamps which in 800 hours only fell from 19 candles to 16·5, why is it that such lamps are not made and sold at the present day? One other question is, what is the cause of the falling off of the light of a Nernst lamp? I should like to know that very much. One knows that in the case of the ordinary glow lamp it is due to a change in the surface of the carbon filaments, by which it becomes a worse radiator of light, and sends off the energy at a lower temperature. Does anything like that occur to some extent on the Nernst filament? Does its surface change so that as it ages, say after 100 or 200 hours, it gives off energy at a lower temperature? Or what is it that happens? Is it a change in its nature which causes what must be the common experience of many present, namely, the light to fail and not to remain, as I wish it did, following the curve such as Mr. Drake has indicated? Professor Ayrton.

Mr. M. SOLOMON: I should like to add a few remarks to what has already been said on the Nernst lamp, especially with reference to Professor Ayrton's comments on the candle-power curves shown by Mr. Drake. Of course one does not always get such good results as these, especially so good as those in the curve in Fig. A, which represents the mean result of tests on three lamps. That curve does drop a certain amount, and the curve in Fig. B drops rather more, but perhaps the average curve obtained with the commercial lamp of to-day drops more than either. Still I would point out one fact with reference to judging the performance of the lamps by those which one sees burning in shops, namely that in the first part of the curve there is a very marked drop in candle-power from about 130 to 110. My experience is that there is always a drop corresponding to that, though not perhaps always so great, and sometimes a little greater. The result is that after the first 50 hours the light from a Nernst lamp seems to change a good deal in colour on account of this first drop. The light is a very white one at first and remains white during the whole life, but one notices a considerable difference in shade if two lamps, one new and one 50 hours old, are observed side by side. But after that drop the candle-power remains fairly steady, as shown by the curve, which is quite a typical one. When the curve drops off sharply towards the end it is a sign that the lamp is about to fail. Mr. Solomon.

It is interesting to note in connection with the curves in Figs. C and D showing the behaviour of the iron resistance and the increase of candle-power with increase of voltage, that one may actually lose in efficiency by over-running a Nernst lamp. The reason is obvious when you think of it, for if the lamp is over-run by 15 per cent. the candle-power is only increased very slightly, but the volts taken by the

Mr. Solomon.

resistance are increased by a very great amount. The result is that the percentage of the total volts, and therefore the percentage of the total watts, absorbed by the resistance is very much greater, and the actual over-all efficiency of the lamp I have found usually falls when the potential difference at the terminals is increased. This is clearly shown by the curves in Fig. E, which are for a half-ampere 200-volt Nernst lamp. It will be noticed that the total watts per candle increase slightly when the supply pressure is raised above the normal. Therefore it is of course not only inadvisable but useless to try to get more out of a Nernst lamp by over-running it. The curves for the iron resistance have already been referred to by Mr. Drake, and also by Mr. Swinburne in his presidential address; they are very remarkable curves, and the Nernst lamp, by leading to the invention of this iron resistance, has given us what is in some ways a new piece of electrical apparatus, which may be of great use in other classes of work. One

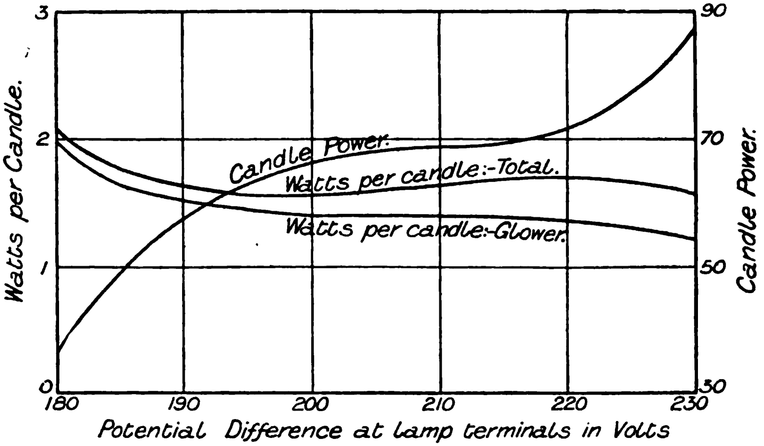


FIG. E.

can, for example, use these resistances in series with an arc, and one can get certain results by so doing which it is very difficult to obtain in other ways. If a resistance of this sort is used it is possible to run an arc with a very low current more steadily, and on a circuit of lower voltage than is possible with an ordinary resistance. I have tried this experiment, and succeeded to a certain extent, though there are certain difficulties in the way. The explanation is clear if one considers the curves for the arc which were first published by M. Blondel, and which Mrs. Ayrton has made familiar to us all. The resistances can also be used with ordinary glow lamps, and it might be a great advantage to use them with the standard incandescent lamp described by Professor Fleming. It would do away with the objection which must militate against the use of a carbon lamp as a standard, namely, that the candle-power is so sensitive to the voltage; by using a resistance of this sort one gets a curve similar to that for the Nernst lamp in Fig. D, and one

can get much better working results for practical purposes in this way and can dispense with the trouble of having to use a potentiometer. Mr. Solomon.

I should like to refer to one other matter. Mr. Drake called your attention to the two-glower lamp which is shown on the table: there is also exhibited another two-glower lamp in which the glowers are arranged in series, so that it runs direct on a 400- or 500-volt circuit. This lamp has been run and tested, and it worked extremely satisfactorily on a 500-volt circuit.

Professor AYRTON: Will Mr. Solomon add, to the interesting information he has given, one fact? The lower curve is of such enormous importance that I wish to ask this question. It is a curve showing that under some conditions the Nernst lamps are as good as far as their life is concerned, as a very good ordinary carbon glow lamp, but giving a higher efficiency. I want to ask, did you require much more heating to make that particular Nernst filament glow? Did you expend much more power in your heating coil than you do with an ordinary commercial lamp so as to start the glowing of the filaments which were used in those six lamps? Professor Ayrton.

Mr. SOLOMON: In answer to Professor Ayrton, I may say that those lamps were perfectly ordinary Nernst lamps, and had exactly the same heating coil as the commercial lamps which the Nernst Electric Light, Ltd., were then making. This coil took practically the same current as the modern commercial lamp made by the A.E.G. Mr. Solomon.

Mr. E. B. VIGNOLES: I want to ask one question with regard to a point which has not yet been touched upon this evening. It has regard to the liability to damage due to variations in the voltage on the lamp terminals. With the instructions which the Allgemeine Elektricitäts-Gesellschaft send out with their lamps is a statement to the effect that the voltage on the lamps must be kept steady. My experience of these lamps is limited, but I have found that with the ordinary, more or less unsteady, voltage which is provided in my factory for the purposes of lighting the lamps gave out in a very short time. Will Mr. Stöttner tell us to what extent the voltage may be allowed to vary with impunity, and whether the rapidity of variation in the voltage has any effect on the lamps or their resistances? For instance, if I put the lamp on to a dynamo driven by a gas engine which is varying frequently to the extent of, say, 5 per cent. of its voltage, is the lamp likely to give out quickly? It would appear from the breakdowns to which I call attention that the fine iron wire is run at such a temperature that quite moderate variations of voltage are sufficient to destroy it: and this defect seems serious, in view of the fact that on any supply a temporary rise of voltage is liable to occur. Mr. Vignoles.

Mr. A. A. C. SWINTON: Another point with regard to which I think it would be desirable to have further information is, the comparative results that can be obtained with these lamps with continuous currents, and with alternating currents. Personally, I have had a satisfactory experience of their working with continuous currents in my office. But in other places where I have had them tried and the current is alternating, with a frequency of 80, the results have not been good at all. Now, what I am anxious to know is this: Is this difference in Mr. Swinton.

Mr. Swinton.

result due to something inherent in the alternating current, or is it due to what I think may possibly have been the fact, that with the alternating current the voltage was not quite as steady? I have my office in Victoria Street, and I am supplied by the Westminster Company, whose voltage is exceedingly steady, but I rather fancy that there is something in alternating current which does not agree with these lamps. That is only surmise on my part, however. With regard to the falling off of the candle-power, the scientific aspect of the question has been mentioned by Professor Ayrton. Now the filaments of these lamps are made of materials the same as, or analogous to, those used for incandescent gas mantles; and it is well known to everybody who uses incandescent gas mantles that these mantles fall off very much in candle-power in course of time. I think the reason they fall off is also known. I believe I am right in saying that the Welsbach mixture of which these mantles are composed is about 99 per cent. of oxide of thorium and 1 per cent. of oxide of cerium, and it makes an enormous difference what the exact proportion of cerium is; 1 per cent. makes all the difference in the world. I understand that the cerium is more volatile than the thorium, and that consequently after a time the cerium has a tendency to disappear. In fact, I believe that the ordinary practice of the manufacturers of incandescent gas mantles is to put in too much cerium to begin with, so that really you get the best effect at about the middle of the life of the mantle. At first sight one might think that a similar effect may be the reason for the falling off in the candle-powder of these Nernst lamps, but I wish to put forward a reason which I think makes that exceedingly doubtful. About two or three years ago I made some experiments, which were communicated to the Royal Society, upon the luminosity of incandescent mantles; the mantles were not exactly like those made for ordinary use, but were made very thick, though manufactured in the same way. I heated them to bright incandescence by bombarding them with cathode rays in a vacuum tube; and I found that whereas in a Bunsen gas burner a mantle of pure oxide of thorium gives only something like one-eleventh of the light that is got with a mantle made of the Welsbach mixture, pure oxide of thorium when bombarded with cathode rays gave practically the same amount of light as the Welsbach mixture. There was a slight difference, but the difference was estimated at not more than 5 per cent. We had a patchwork mantle made, half of one and half of the other, and when we bombarded it equally all over we could barely see that one half was brighter than the other. That goes against the theory of evaporation and consequent alteration in the mixture being the cause of the falling off in the light when the heating is effected by anything else than a gas flame, and I am inclined to suggest that it is probably a change in resistance more than anything else that causes the light to diminish; that the electrical efficiency remains more or less the same, but that the current goes down, and with it the light.

I think this is a most interesting subject, and I have a great belief in the future of these lamps provided that, as I have no doubt is the case, the defects mentioned by Mr. Hammond can be got over by improved manufacture. Further, I think that this question of improved

lamps is one of the most important subjects which can be discussed by this Institution. Mr. Swinton.

Sir Henry Mance. Sir HENRY MANCE: With reference to the inquiry as to the amount of current taken to warm up the heater, I may say I have tested these lamps for some thousands of hours at my private residence, and have found that the heating current was rather more than that which the lamp took after the heater was cut out of circuit. With regard to suitability for alternating currents, my house is connected to the mains of the Brompton and Kensington Company, which supplies alternating current at 100 volts, the pressure being extremely regular. I daresay I have tried at least 20 or 30 of these lamps; I have found their life varied from 150 up to 800 hours. One of the causes of failure, as already stated by Mr. Hammond, was that the lead up to the glower failed just at the point of contact; and I made the suggestion that the contact should be arranged in the form of a ring, so that if the lower portion of the ring gave way there would be still remaining the upper portion of it, and the life of the lamp would be thereby prolonged. I noted the current which all these lamps took very carefully, and I think the statements which have been made by the inventor and those interested in the exploitation of the Nernst lamp have been fully borne out. As chairman of a company which supplies electric current, you might perhaps think I am afraid of the effect that the lamp might have on our revenue. But I myself welcome anything which will cheapen and popularise the use of the electric light. There is no doubt that the lamp takes one half the current of the present lamps, but I think that long before the conservative British public have taken to the use of the Nernst lamp they will have been educated up to requiring twice the amount of light.

There is one rather important point which perhaps the author might assure us about, and that is, how the lamp stands transport? I made some experiments myself with the replacement pieces in the earlier days, when the lamp was nothing like so perfect as it is now. The results of these experiments were not altogether satisfactory. This is a most important point, as the lamps have to be despatched to the furthest corners of the world.

Mr. Drake. Mr. DRAKE: I would like to answer Professor Ayrton's question. The bottom curve was taken with lamps which started with about 2 watts per candle, instead of 1·7. Everybody tried to make the Nernst lamp do more than it could do; and we made experiments to see if it would not be better in the end if we started at 2 watts, rather than 1·7 which gave such a rapid drop in candle-power. We certainly got a better result than is obtained from the lamps which are now being put on the market.

The President. The PRESIDENT: We have had this evening a very interesting discussion. We have had Mr. Stöttner, who represents the German manufacturers of this new industry; and then we have had Mr. Drake, who not only represents the English Company, but is really more than an ordinary Director, for he has done an immense amount of the actual detail work himself with the Nernst Company. And we have had Mr. Solomon, who, with Mr. Sheppard, has also done a great deal of

The President. original work. I wish we could have had something from Mr. Sheppard too. We have not heard anything from the Ganz people on the subject, and we have not a representative here from the Westinghouse Company to tell us what is going on abroad. Before calling on Mr. Stöttner, I would like to say, partly in reply to Professor Ayrton, that the manufacture of these filaments is exceedingly difficult, not only as a matter of ordinary manufacture, but as a matter of very intricate chemistry. One reason why the English Company, though they did not make many filaments and lamps, got, in some cases, particularly good results, was the enormous care they took over the chemical preparation. Any one who is familiar with the chemistry of the rare earths knows it is exceedingly difficult to purify many of them. Some of them can only be purified by continual re-crystallising. And in any case the purification of zirconia, which is one of the chief components, is very difficult. As to the other part of the filament, it is really a group of earths. You can buy "yttria" from a manufacturing chemist, but you can never guarantee that any two bottles contain the same substance. They are mixtures of the same group of oxides, and it is very difficult to know exactly what you are getting. First, there is the mechanical question, and then there is the chemical question. It is apparently, exceedingly important to get the material out of which the filament is made, in a given physical condition, especially to get it sufficiently fine. A slight difference in this way made a great difference in the life and the change of resistance of the filaments.

As to why a lamp should go down in life when, apparently, it is controlled by a resistance which will practically keep the watts in it constant, or nearly constant, that raises a very interesting question. I do not want to contradict Mr. Campbell Swinton, but I think the argument used by him ought to have the negative sign put before it, because the conditions in the case of incandescent gas are exactly the opposite of what they are here. In the case of the incandescent gas lamp, if you increase the emissivity of the mantle you lower its temperature and eventually its candle-power. But the mantle gets more energy and gives more out, because it gains more from the gas, and the whole question is different. What I think probably happens in the case of the Nernst lamp is, that when the glower lamp gets a little old the platinum from the contacts gets into the body and you notice a slight graying of the filament, and this means an increased emissivity and light-radiating power at a given temperature. And if you keep the watts constants it radiates energy at a lower temperature and probably gives less light. Mr. Swinton's experiments in bombarding thoria are not in the least conclusive, either as regards the Nernst lamp or with respect to incandescent lamps for gas. When you are bombarding you cannot tell whether the surfaces are at the same temperature, though they may look so. If you take the trouble you can find on purifying zirconia that eventually you can get a material which you can make into mantles for gas lamps to give almost no light, but they will give plenty as Nernst lamps, and they will give plenty of light when they are bombarded. But that is a different thing, because when you are bombarding you have not necessarily got them at the same temperature.

Earl RUSSELL (*communicated*): Not being able to get into the room to take part in the discussion, I am compelled to send some observations in writing. The Nernst lamp is a very fascinating invention, and the account by Mr. Stöttner is very interesting, as I do not doubt the exhibits were if I had only been able to see them. The lamp is economical, and the light given by it is of a very pleasing quality. But I am afraid a great deal has yet to be done in making the burner run for a sufficient time. I have two Pattern A 1902 Nernst lamps, and my experience with them has been unfortunate. The lamps are 105-volt, and they are run from accumulators only in which the usual pressure is 101 to 102 and never exceeds 104, so that they are not over-run. Nevertheless, I find that instead of a life of, say, 300 hours, as stated in the catalogue, the average life has been something like 20 hours. The longest that any burner has run is about 3 months during the lighter part of the year, representing perhaps 180 hours. On the other hand I have had two burners going the next day after being put in: two which refused to light at all, and three or four which had gone in periods varying fron 9 hours to 40 hours. It is only fair to say that so far the Electrical Company have been most generous in replacing these early failures without charge, but of course one cannot say how long that will go on. They practically always break at the same place, that is the spiral part near the bottom. Another objection to their commercial use at present is the limited range of candle-power, *e.g.*, you cannot get more than a 60-candle lamp on a 100-volt circuit. Although the replacement is easy, still it involves time and annoyance (particularly if it has to be done in the dark) and the fetching of a pair of steps, besides the cost of 2s. 6d. a burner. Until, therefore, a longer average life can be given to the burners, I fear the lamp can hardly be regarded as a success for use in private houses. Earl Russell.

Mr. A. WILSON (*communicated*): I am disappointed to find in the paper no statement as to the average life of the burners and resistances of the Nernst lamps as at present placed on the market, and should be glad if the author would give some information on that point. The Company who have introduced these lamps have stated in one of their pamphlets that the life of the burner averages 400 hours, but experience with a considerable number of lamps leads me to believe that 200 hours is a long life, and even that can only be attained by running the lamps considerably below the total volts for which the combined burner and resistance are marked. For example, in a factory in which over 100 lamps are used, with 220-volt burners and 20-volt resistances and with *never more* than about 240 volts at the lamp terminals, the engineer in charge stated that the average life of the lamps was about 40 hours. By using a 255-volt combination, *i.e.*, 235-volt burner and 20-volt resistance, and consequently under-running the lamp by 15 volts, the life has been raised to about 200 hours, or about half of what it is supposed to be, with, of course, a corresponding reduction in the efficiency of the lamp. Mr. Wilson.

The lamps undoubtedly give good light and are of high efficiency, but the unreliability of the burners and the amount of attention required in making replacements seems more than to balance any

Mr. Wilson. economy which they are supposed to effect. I am quite unable to reconcile the statements which have been published as to the life of the lamps with my own experiences and those of many others under ordinary working conditions, and take this opportunity of asking for a statement on the matter from one who is apparently intimately associated with the manufacture of the lamp.

Mr. Stöttner. Mr. J. STÖTTNER, in reply, said: With regard to the remark made by Mr. Drake about two filaments in one lamp, the construction is shown in Fig. F.

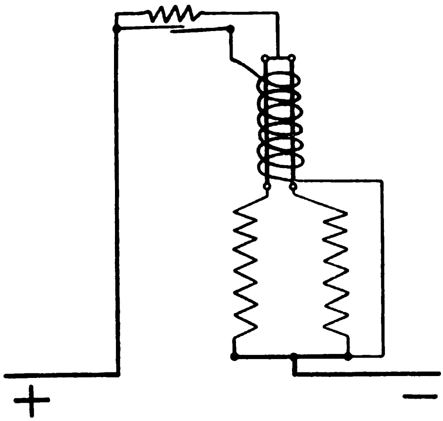


FIG. F.

We put two filaments, which are connected in parallel, inside the heater, the current passing through one automatic cut-out to the other pole. One or other of the two filaments will be heated first—it is immaterial which—and as soon as one is incandescent the heat radiating from it will start the other filament and make it also a conductor, so that there are two filaments and one conductor. Another advantage of this arrangement is that if one filament breaks, or for some reason goes off, the other is always intact and will act as if nothing had happened.

The burners with horizontal filaments are a further novelty, they are shown in Figs. G, H, K, and L.

The filament is in front of the heater, so that all the light radiates directly downwards; they can be arranged in any number. In these lighting bodies the filaments can be taken out and easily exchanged, the complete burners being fixed in the body of the lamp as in the present design. The filaments are exceedingly simple and provided with flexible conductors, which carry a small plug on each end for connecting up. One hundred filaments can be got into a match-box.

Mr. Hammond, I am very glad to say, got about the same results as the Physikalische Technische Reichsanstalt, which worked out the average life of a lamp at about 450 hours, while Mr. Hammond got 305 hours. Had he had such clever experts to handle the lamps at

Hackney as they have at the Physikalische Technische Reichsanstalt, the results would doubtless have been still better. The reason why the flexible at Hackney and many other places has failed is a very simple one. Mr. Stöttner.

FIG. G.

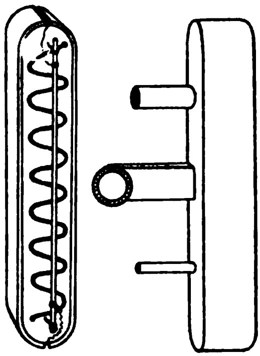


FIG. H.

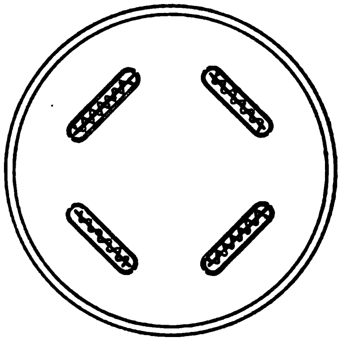


FIG. K.

The heater-coil, Fig. M, expands somewhat as soon as it is up to temperature, and if the flexible wire *a*, which conducts the current to the filament, is bent and touches the heater, it either burns through at *b*, should there be a bright spot in the heater spiral, or it burns the heater wire through, as the resistance from *b* to *c* is very small. There would,

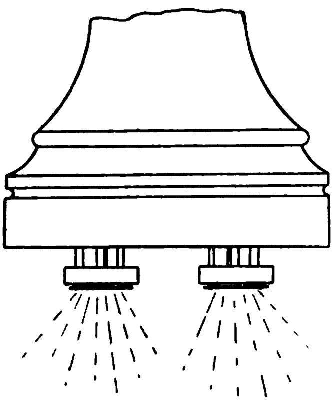


FIG. L.

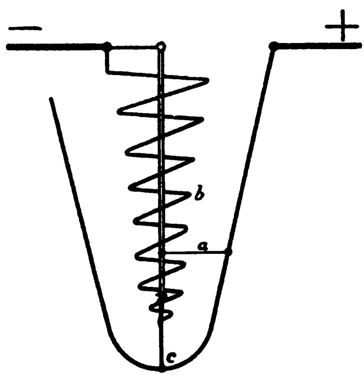


FIG. M.

however, be no difficulty in taking such a slight precaution as to examine the filament after insertion. If the lamp does not light up, the automatic cut-out does not act properly. The filaments and heaters must be examined before they are put in, and if the heater does not cease glowing as soon as the filament is incandescent, the contact-spring of the automatic cut-out sticks and the inside of the lamp must be examined.

Mr. Stöttner.

As mentioned by Mr. Swinburne in reply to Professor Ayrton, the efficiency-curve of the lamps which Mr. Drake showed is very high. We have not found such very high efficiency in ours. The light certainly does go down after a lamp has been in use for a considerable time, and the filament takes longer to heat up than it does when it is new. The efficiency drops considerably because of the blackening of the heater-coil and further on account of the crystallisation in the filament, as is shown by a filament on the table before me, which has burned 1,600 hours. As to the variation of voltage, 5 per cent. does not make any material difference to the life of a lamp, but it is preferable for it to go down than up. There was one station mentioned, however, where the variation is a good deal higher than 5 per cent. There may be a 20 per cent. variation. If the voltage rises too high, the result is that the bolstering resistance burns through. It acts as a kind of safety-fuse to the lamp if everything else is properly arranged.

As touching the question whether alternating- or direct-current lamps are the better;—*theoretically*, alternating-current lamps should be better but *practically* we find that direct-current lamps give greater satisfaction. Whether this is because at the works the demand for alternating-current in proportion to that for direct-current lamps is about 1 : 500, and less experience has been gained, or whether there is some other ground for this, I cannot say. The breaking of filament is generally due to mechanical causes. Either they get knocked about, or they break through vibration or through some other part of the lamp not acting, as already mentioned. The electrolytic effect on the filament will in every case be exactly the same. There is no reason why one filament should burn out more quickly through electrolysis than another.

One speaker mentioned the packing and transport, which is a very serious question, under which we have to suffer greatly. As a test of average breakage we took two packages and tumbled them down four flights of stairs. On examination we found in one case two burners broken out of 200 and in the other case five broken out of 400, which I do not think is a very great percentage. With the new packing it will be less still. The old packing was much less suitable for rough handling in transit. I once caught one of our boys tossing three of the old-style round boxes with burners like a juggler, which at once explained to me why some of the filaments break; and other people may have similarly playful boys in their employ.

The President.

The PRESIDENT: I will now ask the meeting to pass a very cordial vote of thanks to Mr. Stöttner; and I have his authority to mention that he hopes to present to the Institution museum, samples showing the early history of this lamp.

The vote was carried by acclamation.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected, viz.:—

Member.

Wilson Hartnell.

Associate Members.

Frank Bradford.
Ashton Bremner.
Henry Coulson-Crawford.
James Cuninghame.
Albert William Davies.
Raymond G. Mercer.
Andrew Home Morton.
Frank J. Robins.

Associates.

Augustus George Ashton.
Malcom Rayner McClure.

Students.

Arthur McL. Atkinson.
Herbert Frederick H. Blease.
John Henry Clarke.
Ernest Francis Cutforth.
James Floyer Dale.
Walter Hugh St. A. Davies.
Oswald J. Davis.
Harold W. Fulcher.
Henry J. Golding.
George Goodwin.
Ernest James Harper.
Laurence E. C. Harrison.
Herbert H. Harter.
David Cecil Henderson.
Frederick Richard Hobley.
A. T. S. Hore.
James G. Horgan.
E. Laubach.
Horace Hamilton Leage.
William E Cato Liebert.
Wyndham d'Arcy Madden.
Arthur Cecil Morrison.
Ernest William Moss.
Llewellyn Digby Odlum.
Hugh Prideaux.
Hubert G. Ross.
Henry Eustace Sayer.
Herbert John Seale.
John Franklin Shipley.
Chas. Francis Simpson.
Benjamin Spalding Smith.
Joseph James K. Sparrow.
Wm. T. Tallent-Bateman.
David Alan Trickett.
Eric Charles B. Walton.
Eric Gordon Waters.
Thomas Douglas W. Weston.
Arthur Penry Williams.
George Stewart Wilson.

NEWCASTLE LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN.

By Mr. J. H. HOLMES, Member.

(*ABSTRACT.*)

(*Address delivered November* 17, 1902.)

In addressing you at this, the third inaugural meeting of the Newcastle Local Section of the Institution of Electrical Engineers, I wish, in the first place, to thank you for the honour you have conferred upon me by electing me to the position of your Chairman for the ensuing session.

I have no doubt that with your cordial support and assistance I shall find the duties appertaining to the office as agreeable as they are honourable, and that our united efforts will enable us to uphold the status of the Institution and make the session a success. In the remarks which I have the privilege of addressing to you by way of opening our proceedings, I propose to glance at the influence exercised by the great activity and rapid development of electrical engineering upon other branches of the engineering profession.

We all have the honour of belonging to the noble profession of the engineer to which modern civilisation owes so much. For, whether it is within the sphere of the domestic circle or without, in the strenuous life that daily confronts us, there is scarcely a comfort or a convenience that exists to the realisation of which the engineer has not largely contributed. Engineering has been defined as the art of directing the great sources of power in nature to the use and convenience of man, and therefore the engineer is interested in every investigation and discovery in the whole realm of science—his occupation is the most catholic of all. No sooner does an abstract theory become a demonstration than the engineer seizes it and applies it to man's uses.

Some discoveries burst upon us with a blaze of light attracting universal attention, and inventions follow with lightning speed, whilst others develop so slowly as almost to pass unnoticed.

The branch of engineering with which we are so intimately concerned, whilst most far-reaching in its consequences, is, when measured by the mere lapse of time, but of recent growth, yet, measured by its phenomenal progress, is quite ancient, and already embraces so many distinct branches that it has become practically impossible for one man to keep pace with the developments almost daily occurring in its many sub-sections.

Young, however, as the profession of electrical engineering is, I think we may justly claim for it, that it has exerted a greater

influence upon engineering as a whole than any other individual branch, and we may profitably spend our time by glancing at a few instances of the kind.

A dynamo, as we all know, is the agent by which mechanical power is converted into electrical energy. The prime mover is usually a steam engine which has a reciprocating motion, which, by the aid of a crank, is converted into a turning movement. By the very nature of things an unequal torque is the consequence, leading to a pulsatory motion of the dynamo. There is no more exacting duty for a steam engine than that of driving a dynamo for any purpose, but particularly for lighting, where a pulsation or rising and falling in the intensity is most distressing. Hence in the early days to drive a dynamo by means of the existing engines was like driving a square peg into a round hole, and the steam engineers were immediately confronted with the problem of how to get a uniform angular velocity which was extraordinarily important in running alternators in parallel. It is interesting to recall the various methods employed to meet the case. How eagerly the problem was struggled with more or less satisfactorily in many different ways.

The early dynamos were run at high speeds obtained by belt-driving through gearings or countershafts, which was soon recognised as wasteful of power, and the difficulty was met by increasing the engine speeds, which drove out the large long-stroke slow-moving heavy engines in favour of small short-stroke quick-moving light engines driving by belting direct from the flywheel. But this was not enough, because dynamos had a variable load, hence the makers of small engines were compelled to introduce improved governors and heavy flywheels. These took the form of high-speed throttle governors spring-controlled, only to be superseded by automatic expansion governors, which, in their turn, were replaced by shaft governors revolved at engine speed.

Heavy flywheels on engines used specially for driving dynamos for traction purposes, where the alterations in load are both frequent and rapid, did very good service, securing a relatively constant angular velocity for that class of work.

To sum up, the dynamo with its high speeds forced on the balancing and governing of steam engines to a point that was never dreamed of as necessary before.

Another problem was that of lubrication. Continuity of run over long periods called attention to the need for unfailing lubrication, the oil cup of old being superseded by centrifugal oilers, and a few hours' run being lengthened out into fifteen or more, and finally to continuous running, as in the marine engine. This led to the employment of pipes and wipers fed from oil-cups, and later from a central oil-box with sight feeds. Then to independent oil-pipes to each bearing surface, conveying oil at a pressure of 20 lbs. to the square inch, maintained by a force pump. And perhaps in the most advanced way in enclosed engines such as the Willans or Chandler, where the moving parts practically splashed about in a bath of oil and water, effectively lubricating all the bearing surfaces. However, all experience having

shown that the balancing of parts, the perfection of lubrication continuity of run, small occupation of valuable space, and absence of great watchfulness as essentials in electrical machinery in up-to-date power-houses, it is brought forcibly home to every one that in Parsons' turbo-generator, which has been gradually developing of recent years, these qualities are embodied, combined with a reasonable steam consumption, to so great a degree as to bring the Hon. C. A. Parsons' invention into the foremost rank of all prime movers, and I am sure I voice the feeling of all in being proud to note that our esteemed member has been awarded the Rumford Medal by the Royal Society in recognition of his important work. Useful as this steam turbine is in electrical work, its application to marine propulsion bids fair to rank as a still greater achievement.

Measurement of Power.—The simplicity and exactitude of electrical measurements has exerted a very great influence upon questions relating to the efficiency of steam engines, both as regards steam consumption and the internal losses in the engine itself.

Water Cooling.—How to cool water for condensing purposes, that great aid to the economical application of steam power, is one of the electrical engineer's difficulties in cities where cooling ponds and running streams are absent. This has been met by the introduction of cooling towers, economical at their load, and certainly a fairly successful mode of meeting what is a difficulty in most cases.

Gas Engines.—Strange as it may seem, it is nevertheless true that it was many years before the electrical engineers could convince the gas-engine makers that the pulsation in lighting from gas-driven dynamos was not inherent to the dynamos.

In the Otto cycle method of working, where the compression of the mixed gases before ignition is a great improvement, in the single-cylinder engine, as only every fourth stroke is effective (the other three absorbing energy stored in the flywheel), a variable angular velocity results. This is met by high speeds and very heavy flywheels placed on the engine, which is the right place, and not on the dynamo spindle, which is the wrong place.

As the heating of gas-engine cylinders is proportional to the work done, over-heating had to be met by water jacketing, involving increased tank capacity and more room for the extra cylinders, a condition unknown in intermittent work for which the gas engine was in the main designed in the first instance.

Quite recently, large power producer-gas engines, such as the "Diesel," consuming crude petroleum finely sprayed into the combustion chamber, have been introduced highly suitable for driving dynamos with economy.

Transmission of Power.—In the transmission of mechanical power I claim that the electrical engineer has exercised extraordinary influence.

Belting.—The increase of transmitted power through using higher speeds in running shafting and belting was but dimly recognised until forcibly brought under notice by dynamo working.

Inequalities in laced belting joints caused jerks in running over

dynamo pulleys, and led to endless sewn joints for smoothness in running and dynamo slide rails for taking up the slack caused by stretching.

Then to obtain greater equality and avoid slip the leather link belt was devised, each link becoming a joint. The extra weight of this form of belt was of advantage when used with the top side slack, as it should be, as its sag embracing a larger arc of contact on the pullies reduced slip, even when the shafts were comparatively close together. But a laminated belting composed of long strips of leather placed on edge side by side until the required width is obtained, then closely sewn through, best fulfils the requirements for the transmission of power.

Small Steam Pipes.—The great economy in the electric transmission of power by means of wire conductors has opened the eyes of the owners of works to their losses in that most wasteful method of power transmission by distributing steam from a central point by means of steam pipes, either underground or overhead, to small engines at a distance. Enterprising men, especially shipbuilders, have realised large economies, first by diminishing labour by concentrating their generating plant in one shop, and, secondly, by replacing their notoriously inefficient scattered small steam engines by electric motors deriving their energy from compound or triple condensing engines. The electric motor only draws energy as the work needs it, the waste in distribution by electric conductors is trifling, the daily upkeep is small, and the arrangements are simple in control. These advantages presage the early supersessions of steam-power distribution, and also of hydraulic-power distribution. Lifts or elevators are now mostly electrically worked, and cranes and capstans for docks and warehouses are rapidly following suit.

In overhead travelling cranes the usefulness of three motors *versus* one motor is moving in favour of three motors, because of the peculiar feature of electric driving previously mentioned—the absence of loss of energy excepting during actual running of the motor which exactly fits intermittent work.

The slow speed of the chain drum has called for improvements in gearing, leading to the use of raw-hide gearing, double or triple thread-worm gearing running in an oil bath, of friction gear, and in some cases the epicycle train.

The propulsion of vehicles is of immense importance, and the electric influence is daily more marked. Indeed, it is evident that we are on the threshold of huge developments in this direction.

Even the large railway companies have been stirred, and it looks as if Newcastle, the birthplace of the locomotive, will also be the pioneer in the use of electric haulage. If not, it is safe to predict that the electric tramways service, which is now developing so marvellously, will still further diminish their receipts.

Electric tramways must work a complete revolution in social life, inasmuch as their cheap rapid and pleasant transit brings town and country into closer touch, spreading the population over a wider area, discrediting jerry-built flats in favour of garden cottages.

For all automobile work electricity is by far the cleanest and most agreeable agent, and much development may be looked for in this direction.

Socially, the influence of the electric light has been most marked; it has lent brilliancy to internal lighting by the use of the arc, and for decorative purposes the glow-lamp is supreme, whether it be for advertisement or for social gatherings. It has stimulated the use of light; that which used to be considered sufficient is now considered inadequate, what would formerly poison the atmosphere and dirty all decoration now simply makes home cheerful, and vitiation of the air is overcome whether in the theatre or the home.

The reaction upon the gas industry has been immense; the gas man's monopoly has gone, and with it his lethargy, leading to the regenerative gas-burners of Siemens and Wenham, and the Welsbach light; and, latterly, the Kitson modification of the Welsbach, with its low cost and rivalry of the electric light? Similarly in fittings, the artistic designs in graceful lines to please architects have stimulated similar improvements in gas-fittings. And as to ocean steamers, what would they be without the electric light? and shortly what will they be without electric winches, windlasses, fans, which are fast superseding small engines and leaky steam-pipes?

Then, again, what an influence electric search and other lights have had on the mercantile marine, doubling the capacity of the Suez Canal without cost, where 90 per cent. of the vessels that pass through save fourteen hours per trip by its agency.

The coal miner now signals, blasts, and lights electrically; also pumps, hauls, drills and cuts his coal electrically.

The gold miner converts water power into electric power, and by its agency crushes ores and uses it for all mechanical purposes.

Edison separates iron ores formerly useless for the smelter, and electricity plays a prominent part in reducing and refining, whilst the electric furnace also produces aluminium, sodium, carborundum, and calcium carbide now, and will, probably, other substances shortly.

Of course of the oldest of the electrical industries, telegraphy, and its development telephony, much can be said; what was a luxury is now a necessity almost as much as the sun itself, for by its commercial agency the business of equalising the products of the world for feeding its inhabitants is consummated.

As for wireless telegraphy, with which Marconi's name is linked for ever, it should be as useful to fleets at sea as the ordinary telegraph is to railways on land, and what more may be in store only time will reveal.

Again in the case of the body, for nervous troubles, for baths, for cauterising, for ameliorating skin diseases and looking into our interiors with Röntgen rays, how can we do without it?

I trust this rapid glance at some of the instances of the influence of electrical on other branches of engineering has served to remind us that we belong to a profession which, though young, has played an important part in the march of progress recently, and promises a more rapid advance than ever now. Electricity now permeates every

branch of business ; it is no longer an abstruse science, and every one who takes an intelligent interest in what goes on around him must acquire some knowledge of its behaviour and uses.

By creating new needs electricity has stimulated the other branches of the profession in a very marked manner, quite beyond the stimulus of competition in their own lines.

It would be too big a subject to enter upon the question as to how far our present standard of civilisation would be possible if electricity were absent from our calculations, and I must leave this for each of us to think out for himself.

If I have succeeded in impressing upon any one of my hearers a higher opinion of the usefulness and importance of the work upon which he is engaged, and of the nobility of his profession, I shall be amply repaid for what, after all, are, I fear, but feeble efforts to do justice to a theme which is worthy of a much abler pen than mine.

BIRMINGHAM LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN,

By MR. HENRY LEA, Member.

(*ABSTRACT.*)

(*Address delivered December 10th, 1902.*)

From time to time, particularly since the advent of electricity as a producer of light and a distributor of motive power, we English engineers have been charged with being laggards. I am not one of those who believe that we are in a bad case, and I propose to try this evening to ascertain whether the state of one industry at all events, namely the electrical industry, is calculated to afford encouragement to ourselves and the country generally, or whether the gloomy views so often expressed are in any sense justified. My aim this evening will be to obtain a general idea whether the Electrical Industry is growing, or standing still, or going backwards. The period selected for scrutiny comprises the years 1898—1901, four years being quite enough, in my judgment, to show which way the stream is flowing.

The first point that I shall bring before you relates to the growth of the manufacture of steam engines for driving dynamos. Nineteen large firms were good enough to respond freely to my inquiries. The results which I shall place before you are the collective totals of the returns of all the firms who have been good enough to give them in each case, and whilst they must not be taken as being in any sense the totals of this country's production, they may, I think, be fairly regarded as representative of the industry generally.

STEAM ENGINES.

Confining myself then at present to steam engines made by nineteen firms only, I find the following results :—

1. *Numbers of Steam Engines turned out for the sole purpose of driving Dynamos :—*

1898.—967.
1899.—1,649, an increase of 71 per cent. over 1898.
1900.—1,655, an increase of, say, ½ per cent. over 1899.
1901.—1,836, an increase of 11 per cent. over 1900.
1901 shows an increase of 90 per cent. over 1898.

2. *B.H.P. of the same Engines in nearest round numbers :—*

1898.—86,000.
1899.—168,000, an increase of 96 per cent. over 1898.
1900.—210,000, an increase of 25 per cent. over 1899.
1901.—295,000, an increase of 41 per cent. over 1900.
1901 shows an increase of 243 per cent. over 1898.

The extremely rapid growth in horse-power as compared with the much slower growth in numbers of engines indicates that the sizes of the engines are increasing. Thus,

3. *Average Horse-Power per Engine* :—

1898.—89 H.P. each.
1899.—102 " " an increase of 15 per cent. over 1898.
1900.—127 " " an increase of 26 per cent. over 1899.
1901.—161 " " an increase of 24 per cent. over 1900.
1901 shows an increase of 81 per cent. over 1898.

I think you will agree that, at all events as regards steam engines for producing electricity, there has been nothing during the last four years to dishearten the people of this country

CONTINUOUS-CURRENT MACHINERY.

Now let us turn to the output of dynamos and motors, taking first continuous-current machines. In this connection the number of firms furnishing returns is 17 only.

1. *Numbers of Continuous-current Machines, including both Dynamos and Motors* :—

1898.—2,540.
1899.—4,736, an increase of 86 per cent. over 1898.
1900.—5,095, an increase of 7 per cent. over 1899.
1901.—6,799, an increase of 33 per cent. over 1900.
1901 shows an increase of 168 per cent. over 1898.

2. *Power of Continuous-current Dynamos and Motors in Kilowatts* (nearest round numbers) :—

1898.— 39,300 K.W.
1899.— 65,200 K.W., an increase of 63 per cent. over 1898.
1900.— 83,600 K.W., an increase of 28 per cent. over 1899.
1901.—107,400 K.W., an increase of 40 per cent. over 1900.
1901 shows an increase of 174 per cent. over 1898.

A fact that has become evident during the last four years has been the growth in the use of multipolar machines for continuous currents. The matter is not very well understood, and manufacturers have been largely in the hands of consulting engineers. A multipolar machine can be constructed at low cost to give very high efficiency as regards C^2R losses, but it is a much more difficult matter to get over iron losses. The last four years have seen a great increase of knowledge on this subject. The correct construction and subdivision of the magnet cores, the correct proportioning and the number and size of slots in the slotted armature cores, have during the past four years received increasing attention, so that if we now compare the most economical multipolar machine with the most economical bipolar smoothed-core armature of ten years ago, we find the former has at length equalled the

economical efficiency of the latter; whereas for a long time following the first introduction of multipolar machines, although they were always a better mechanical job they were, on account of their heavier iron losses, behind the older machines in efficiency. Consumers as a rule did not appear to understand this, and demanded the same high efficiency from the modern multipolar that they were in the habit of obtaining from the old smooth-cored bipolar, but, for the foregoing reasons, manufacturers failed for a long time to turn out multipole dynamos or motors within the specified limits of efficiency.

Ten years ago the iron and core losses of the bipolar machines made by several leading firms were under 1 per cent., but the C^2R losses were only kept down to 3 per cent. by the profuse and costly use of copper in the armatures and fields. In these days the same total efficiency is obtained, but the distribution of losses is reversed; the C^2R losses can be kept down to 1 per cent., while the core losses are with difficulty reduced to 3 per cent.

Alternating-current Machinery.

The makers of this class of machinery are comparatively few in number, and as regards three-phase work have not long been engaged in the production of such machines. The most that the returns show is that this branch of British industry is receiving some attention, though real activity of growth has yet to come. Grouping together single-phase, two-phase, and three-phase machines, the following are the results of the returns (from five firms) of generators and motors combined:—

1898.—35	machines,	output	9,322	K.W.
1899.—37	,,	,,	8,974	,,
1900.—39	,,	,,	8,209	,,
1901.—77	,,	,,	8,165	,,

The increase in the output of polyphase machinery abroad is due in the main to the fact that local conditions gave rise to a demand for it, whereas no demand for this class of machinery existed at home. Moreover, the position of the patents is very ill-defined, and few firms here have thought it worth while to lay themselves open to an infringement action simply to be able to fill a limited number of orders for power distribution and mining work. No doubt this position will soon alter itself, though as regards the use of polyphase machinery in ordinary factory work the want of flexibility of speed control militates against its application in this direction, where minute speed regulation appears to be of increasing importance.

Standardisation.

Although there certainly has been a very substantial increase in the output of electrical plant during the four years which I have selected for comparison. yet it is probable that the increase would have been still greater if, a few years ago, the engineering interests concerned could have arranged for a certain amount of standardisation. Consider

two firms of equal size and equal manufacturing capacity, one of which, "A," manufactures 50 patterns, and the other, "B," manufactures 100 patterns, both following the modern principle of manufacturing components and afterwards making them up as the orders come in. With an equal stock of tools for turning out these components, and with equal money value of components kept in stock, the firm "A" that works on only 50 patterns will be able to execute an order for any one of these patterns in half the time that the firm "B" will require that has 100 patterns. Then, as the time for executing the order is shortened, so may, for equal dividends paid, the price per article be reduced. The firm "A" therefore manufacturing in less time than "B," turns over its capital in *pro rata* less time than "B," and consequently may be satisfied with a less percentage of profit, and yet pay an equal dividend. Thus quick delivery and low prices go together and help one another to enable the firm "A" to keep its order sheets full.

I imagine that no manufacturing firm exists that would not, if it could, standardise everything it makes, and work to jigs and templates throughout, but in a new industry experiencing a rapid development it is not possible to standardise at an early stage. The process of the survival of the fittest is going on in its usual relentless fashion, and a too early endeavour to standardise would only mean a heavy loss in the abandonment of superseded special tools, or in the remodelling of them to suit the inevitable alteration in pattern. Between these two sets of imperious conditions, on the one hand the urgent necessity for standardising, and on the other hand the danger of doing so too soon, stands the manufacturer, and happy is he whose customers realise the desirability of establishing standards at the earliest practicable point in the history of the development, and so lend a hand in facilitating the manufacture of interchangeable machines.

The Institution of Civil Engineers, with the Institution of Mechanical Engineers, the Institution of Naval Architects, the Iron and Steel Institute, and our own Institution, have now a joint Standardising Committee in full swing, and there is hope that something may be done in the matter, and that consulting engineers and manufacturers may find themselves able to co-operate towards so desirable an end.

Power Schemes.

This subject is wide enough for a long special paper to itself. I cannot do more than briefly refer to it. The scope for constructive business is enormous. The scope for skill to make all the proposed schemes pay well is equally great. I think it may be taken that it will, generally speaking, be no part of the Companies' programmes to compete with the electric light undertakings in their districts, but, on the contrary, to assist the local authorities to obtain Provisional Orders, and to supply them with power in bulk, which they may retail to the inhabitants of their areas.

Traction Work.

Under this heading I include tramways and light railways, but not railways other than light railways. The progress in this branch of the

industry has been marked, but not nearly so rapid as in the other branches previously referred to. The great growth has yet to come, and there are indications that it will be of vast proportions.

The number of firms who in this country make tramway motors is very limited, but the industry is rapidly growing. From the returns which I have received, the output for the year 1901–2 was nearly 40 per cent. in excess of the output for the year 1900–1. Of the total number of cars now running in England, upwards of 80 per cent. of them have motors manufactured in England, and the importation of such machinery is decreasing rapidly.

I will present to you the growth from two points of view, namely, (1) the mileage and number of cars; and (2) the amount of capital invested.

1. *Route Mileage and Number of Cars.*

ROUTE MILEAGE.

1898.—365.
1899.—478 = 31 per cent. increase over 1898.
1900.—576 = 20 " " 1899.
1901.—777 = 35 " " 1900.
1901 shows an increase of 112 per cent. on 1898.

NUMBER OF CARS.

1898.—2,117.
1899.—2,654 = 22 per cent. increase over 1898.
1900.—3,033 = 14 " " 1899.
1901.—3,821 = 26 " " 1900.
1901 shows an increase of 73 per cent. on 1898.

2. *Capital Invested* (nearest round numbers).

1898	Companies		9,800,000
1899	Companies	11,800,000	
	Municipalities	1,170,000	
			12,970,000
		= 33 per cent. increase over 1898.	
1900	Companies	14,560,000	
	Municipalities	2,750,000	
			17,310,000
		= 33 per cent. increase over 1899.	
1901	Companies	19,750,000	
	Municipalities	10,520,000	
			30,270,000
		= 75 per cent. increase over 1900.	

1901 shows an advance of 210 per cent. increase over 1898.

It may be of interest here to remind you of two examples of tramway work carried out on novel lines. At Wolverhampton we have the Lorain surface-contact system at work, so far successfully, though a crucial test would be a severe winter with plenty of snow and salt. Then in London we have an extensive conduit system about to get to work.

Electrification of Main Lines of Railways.

On the North Eastern Railway a portion of the system is about to be electrified upon a good working scale, and much practical information will no doubt be derived from it later on. It may be regarded as the first attempt in this country to displace existing locomotives. The converted lines will be those running from Newcastle-on-Tyne to Gosforth, with some smaller branches. The main object of the conversion from steam to electricity is to compete with the electric trams, so that the scheme will be laid out as much as possible to look primarily after the passenger traffic.

The employment of electricity for the special purposes of underground railways, or for a new overhead line as in Liverpool, can hardly be looked upon in the same light as the N. E. R. experiment, which is undoubtedly in the direction of displacing steam locomotives from the ordinary main lines of railway in this country. It is, however, a far cry from motor coaches of 160 H.P. each to trains requiring engines to work them capable of developing up to 1,000 H.P., which power can be exerted by some of our main-line engines. The steam locomotive may be doomed, but I cannot help thinking that it will die hard, and I for one shall be very sorry when they are no longer to be seen doing the excellent work which they undoubtedly can do. When, however, this country has been cleared of them, I shall probably not be here to see the result.

A great deal has been said from time to time to the effect that by means of electricity alone and a straight mono-rail track, speeds of 100 miles an hour become possible, and that one reason for this is that the employment of reciprocating parts, as in an ordinary locomotive, prohibits their use for those speeds. In my judgment there is absolutely no foundation for this statement. The only reason why our locomotive engineers have not hitherto enabled us to travel at, say, 100 miles an hour, is that they have never been asked to do so, and if asked, have not had suitable roads with suitable curves and suitable gradients for doing so. If it were decided to run at 100 miles an hour, first of all it would be necessary to lay a straight, or a very nearly straight track built in the very best modern style. They would then probably elect to draw trains of the same length as those proposed to be drawn on the electrical system, namely, one or two long corridor coaches. At 323 r.p.m. a modern locomotive having driving-wheels 6 ft. 6 in. diameter travels at the rate of 75 miles per hour, and this speed is an everyday performance on our main lines. The presence of reciprocating parts does not prohibit such speeds, nor do the engines appear to suffer therefrom. I have it from one of our most eminent locomotive superintendents that the maximum limit might be fixed at 350 r.p.m. Taking, however, the above-named lesser and everyday number of 323 r.p.m., the diameter of the driving-wheels for 100 miles an hour would have to be 8 ft. 8 in., or 11 inches only larger in diameter than the 7 ft. 9 in. wheels, numbers of which are already to be found on our main lines, and doing excellent work. It would be absurd to pretend that a locomotive engine with 8 ft. 8 in. driving-

wheels could be built to take one of our long trains of, say, 14 coaches at anything like 100 miles an hour; but if the train be reduced to the length proposed for electrical propulsion, then a steam locomotive could be built of sufficient power to deal with it, and if the reciprocations of the engine were kept down to the present maximum number per minute, there would be no more difficulty in relation to the reciprocation of the parts than there is now. The conclusion is that it is by no means necessary to fly to electricity for speeds of 100 miles per hour. The steam locomotive will easily give those speeds if they are really wanted on tracks specially laid down for the purpose. The smoothness and steadiness with which one travels at 75 miles an hour, or even at the 86 miles an hour which have been attained on one of our main lines, preclude entirely any apprehension that at a speed of 16 per cent. in excess of 86 miles an hour the smoothness and steadiness would be in any degree inferior upon an ordinary first-class double-rail track laid sufficiently straight for the purpose.

Railway Station General Purposes.

On the London & North Western Railway at Crewe extensive alterations, involving amongst other things the enlargement of the station and junctions, the addition of some 50 miles of sidings, and the erection of a large transhipment goods warehouse, called for some well considered scheme for lighting and working them. For power purposes, instead of enlarging or reconstructing the hydraulic plant, the latter has been abandoned, and electricity alone is used for all purposes. The power-house has a capacity of about 1,000 H.P.

The growing utilisation of electricity for general railway purposes cannot be better shown than by quoting the following instances on the N.E. system: The operation of travelling jib cranes and of capstans at Middlesbrough and West Hartlepool, the equipment of the York carriage works with electric overhead travelling cranes and motor-driven machinery, electric overhead conveyors for goods at York goods warehouse and at Newcastle, electric overhead travelling cranes at the Shildon wagon shops, together with motors for driving punching, shearing, etc., machines; contemplated experiments with the electric lighting of signals at Middlesbrough and Leeds; at York the ticket-printing machines are electrically driven, and at Newcastle the ticket-destroying machine; the new locomotive shops at Darlington are also being equipped with large electric overhead travellers for lifting locomotives, etc., etc.

Railways Points and Signals.

I have included this subject because points and signals require a considerable amount of power to work them with certainty under all conditions, involving the use of electric motors for the purpose. The examples are but few in number, and indeed I am unable to place before you any particulars other than those which Mr. F. W. Webb, of the L. & N. W. Railway, has been good enough to send me. Ten signal cabins at Crewe are now worked or are about to be worked by

electricity. In all they will contain 1,000 levers. One of them will contain 350 levers, the largest signal cabin in the world. The whole are interlocked much in the same way as on the old plan. The use of them does not involve any fresh training of the signalmen. The levers are, in fact, switch levers only, controlling motors or long pull magnets or solenoids, as the case may be, and producing eventually the same results exactly as the old levers produce. How the life of these switches will be affected by the constant sparking remains to be seen, though, if they are made with carbon tips, renewable contacts, and have magnetic blow-outs, it is probable that they will wear well and give but little trouble.

Gas Engines for Driving Dynamos.

I should like to have gone into this subject in considerable detail, but time forbids me to do so. The matter has been recently dealt with by Mr. Humphrey, of the Brunner Mond Company, in a very comprehensive manner, and the present occasion is not at all a suitable one for an attempt to vie with him. One aspect of the case, however, I should like to lay before you. The gas-engine makers of this country, who have turned out thousands of most excellent engines, have for some years past had before them the object lesson of the now almost universal adoption of the inverted vertical steam engine for driving electric generators. The demand arose chiefly from the fact that such engines occupy far less floor space than any other, and that economy of floor space has become of essential importance. Also that it is easy to construct on that system three-cylinder engines with all the advantages of even turning moment which they possess. The gas-engine makers must have realised that eventually large gas engines would run steam engines very hard economically and in other ways, and notwithstanding this they have allowed America to take the lead in producing engines of this type. Any one who has had to do with these engines cannot but appreciate the straightforward simplicity of the three-cylinder arrangement, the ease with which they are started, the excellent governing, and the extremely smooth way in which they run. My firm has had the privilege of engineering a gas-engine generating plant of, eventually, 1,200 H.P. at the Birmingham Small Arms Company's factory, and, being unable to obtain such engines in Great Britain, we were obliged to order them from America. So far, they have given us every satisfaction, excepting on the important point that they were not designed and built in our own country, which I must admit is a truly saddening consideration. There is nothing left for our own makers to do but to copy, unless it be, while following the type lead, to produce something even better than the American engines. Recognising as I do their undoubted ability and skill, I most sincerely hope that we may be within measurable distance of finding that they have accomplished such a highly desirable result.

Measuring Instruments.

Ammeters and voltmeters are the principal measuring instruments

used in the Electrical Industry, and during late years considerable differentiation in the types used for direct-current circuits and alternating-current circuits has taken place. Formerly instruments containing soft iron were largely used for both D.C. and A.C. systems. Now it is customary to employ moving coil instruments in the former, and hot wire or "induction" instruments in the latter. Electrostatic instruments are used in both systems, more especially in high-tension and extra high-tension work. The adoption of moving coil voltmeters on D.C. circuits has much to recommend it, for they are dead beat, quick in action, free from hysteresis errors, and economical as regards power expended in them. The same may be said of moving coil ammeters for currents of moderate strength, but for very large currents the power spent in ammeter shunts becomes a source of expense, inconvenience, and inaccuracy. This arises from the fact that such ammeters require the same P.D. to produce full deflexion whether they are for large or small currents, and as this P.D. is usually about one-twentieth of a volt, the loss in a shunt for 5,000 amperes amounts to a third of a horse-power at full load. This disadvantage is minimised in some cases by using part of a 'bus-bar or feeder as the ammeter shunt. The fact that only comparatively thin wires need be led to the indicating instrument is a great advantage.

For measurements in which high accuracy is necessary the ordinary moving coil ammeter suffers from temperature errors, owing to possible differences in temperatures and in temperature coefficient of the shunt and instrument. Fortunately these errors may be greatly reduced by the use of Campbell's bridge compensating arrangement described in his patent of March, 1901. It is satisfactory to learn that Messrs. Elliott Bros. are introducing this compensation in their "Century" testing sets. Moving coil voltmeters of ordinary ranges have little temperature error, for they can be sufficiently ballasted by series resistance of negligible temperature coefficient.

Hot-wire ammeters for very large currents are open to greater objection, as regards expenditure of power, than moving coil instruments, and in addition to this they are slow in taking up their steady readings even when the current through them is quite constant. This latter defect renders the instrument unsuitable for precise measurements in circuits where the current fluctuates. One means of reducing these defects is to use a series transformer with an unshunted instrument in its secondary circuit.

On high-tension or extra high-tension systems hot-wire voltmeters when direct-connected are very wasteful, owing to a certain current being necessary to cause the deflexion, but here again the consumption of power can be lessened by using step-down transformers.

Electrostatic voltmeters need no step-down transformers or other pressure changing devices, and are extremely economical in power. They have, therefore, come into extensive use in high-pressure stations. An important consideration in connection with alternating-current instruments is their behaviour under different conditions of wave-form, and in this respect hot-wire and "induction" instruments have decided advantages over the soft-iron type. As "induction" instruments take

less power than hot-wire ones, and are usually more robust, they are coming rapidly to the front.

The measurement of power in alternating-current circuits has attracted considerable attention within recent years, and numerous wattmeters have resulted. A large number of instruments has also recently been invented to simplify and expedite the measurement of permeability and hysteresis of iron and steel. The instruments of Drysdale, Searle and Holden are perhaps the most novel of these productions. It is to be hoped that these contrivances will induce users of iron and steel for magnetic purposes to test consignments themselves.

Within my four years period, one instrument has been brought out which, to my mind, is the most interesting that has been devised for many years, and is well worth our attention for a short time. I refer to Mr. Duddell's oscillograph. My admiration of it must be my excuse for bringing it alone before you this evening. Through the courtesy of Mr. Duddell I am able to show you the instrument in operation, and I am very much indebted to Mr. Duddell for the loan of the instrument, and to him and the staff of the Electrical Engineering Department of this University for the trouble which they have taken in setting up the instrument and all the accessories on this occasion.

At the end of the Chairman's address a demonstration was given, showing the capabilities of the Duddell Oscillograph. The experiments were conducted by Mr. Duddell himself.

MANCHESTER LOCAL SECTION.

INAUGURAL ADDRESS OF CHAIRMAN,

By Mr. H. A. EARLE, Member.

(*ABSTRACT.*)

(*Address delivered January* 20, 1903.)

It is with pleasure that I avail myself of this opportunity to express my thanks to you, who, as members of the Institution of Electrical Engineers representing the Manchester Section, have paid me the compliment of electing me your Chairman for the present session. It is a compliment which I greatly appreciate. The growing importance of the Manchester Section of the Institution is most opportune at a time when the electrical industry is making rapid and important strides here. As a centre for electrical works in this country, Manchester and district is now the largest and most important. Moreover, Lancashire and the neighbouring county of Yorkshire will, within a comparatively short period, possess electrical generating stations which will be second to none in the country as regards either size or importance. Besides the large municipal supplies in Manchester, Liverpool, and other towns the Lancashire and the Yorkshire Power Companies will shortly start operations; and, notwithstanding the progress of the past, we may confidently anticipate a development in the future which will surpass anything we have witnessed.

With regard to progress in the past, those who have been associated with Electrical Engineering during the last twenty years have witnessed a development and application which the most sanguine could hardly have anticipated. Within the period named the investigations, inventions, and developments which have chiefly contributed to the advancement of the industry are :—

- The production and commercial manufacture of the high-voltage incandescent lamp.
- The mathematical treatment of the fundamental principles of the electric generator.
- The three-wire system.
- The series-parallel control for traction work, and
- The induction motor.

When mentioning high-voltage lamps, I do not especially refer to the modern lamps of 200 volts and upwards, but to the invention and development of lamps with carbon filaments.

The mathematical treatment of the principles of the dynamo, and the laws which were thereby laid down for its construction, was the most important contribution to the problem of electrical engineering which has been made.

By no means one of the least important points in the evolution of the generator is the universal adoption of carbon brushes, which has so greatly assisted to sparkless running and fixed lead. Various qualities of carbon have been introduced of different resistance and hardness; those of higher resistance and finer grain being found most suitable for high-potential, and those of low resistance and coarser grain for low-potential machines, for, as a rule, no one type of carbon is found equally suitable for a large range or variety of generators.

Incidentally the development of the electrical generator gave a strong impetus to the improvement of the steam engine, and the great accuracy with which electrical measurements can be carried out has been the means of enabling the steam consumption at all loads to be definitely ascertained, and one type of engine to be readily compared with another. This has led to the acquisition of much useful knowledge, and to many improvements in design.

By the adoption of the three-wire system in place of a two-wire circuit, the weight of the copper required to transmit a given power a stated distance, with the same percentage of loss, has been very much reduced, and during the last few years the introduction of incandescent lamps for double the previous voltage has extended the scope of supply on the three-wire system to such an extent that direct-current supply has received a new lease of life, and the competition which at one time existed in this country with the single-phase system has been to a great extent, if not entirely, eliminated.

The series-parallel control for tramway work was one of the great steps which placed electric traction upon a sound commercial footing. By its adoption the units per car-mile were reduced by some 30 per cent., and the maximum current demanded from the station by approximately the same amount, and the great reduction that this represented in the first cost of the generating station and in the cost per car-mile is well known to all engineers.

The induction motor, and the branch of electrical engineering to which it is allied, is the present day development of the alternating-current systems. For many reasons three-phase machines have not been so largely adopted in this country as in some others. The increasing size of stations and the increasing need for placing them further out has, however, given rise to an increasing demand in this country for polyphase currents. But there is no rivalry between the direct and polyphase systems; each has its proper place.

A review, however superficial and short, of past progress may well cause us to ask what degree of perfection have we arrived at, and what may we anticipate for the future? New discoveries and developments generally tend to simplification, and the operations by which a given purpose is effected are generally reduced in number as experience is gained and as the problem dealt with is better understood. If this could in any way be accepted as a law, a brief consideration of the present method of generating light would indeed prove that our procedure is most primitive; for it is evident, even to the most uninitiated, that we obtain our light by an exceedingly roundabout process, and that being so, we cannot expect that it should be highly

efficient or economical. A brief consideration will show the result which is attained.

Taking coal having a calorific value of 14,500 units per pound, and assuming 9 lbs. of steam to be evaporated to 160 lbs. pressure per pound of fuel, the efficiency of the boiler and economiser is, approximately, 72 per cent. An engine taking 13 lbs. of steam per I.H.P. has an efficiency of about 17 per cent., or a combined efficiency with the boiler of approximately 12 per cent.; and, assuming the ratio of the B.H.P. to the indicated power of the engine to be 90 per cent., we find that the ratio of the useful return in B.H.P. to the heat units in the coal is represented by 10·7 per cent. Now 7 per cent. of this figure is lost in the generator, giving an efficiency of E.H.P. coal burned of 10 per cent.

The heat units in the coal have been very inefficiently utilised, but what happens during the operation of converting electrical energy into light? From investigations which have been made in connection with the energy consumed by an incandescent lamp, it has been shown that only a small portion of the total radiation is luminous and capable of affecting the eye as light. Taking this portion as 5 per cent. on the average, we find that of the total heat units in the coal practically the whole are dissipated, and only a remainder of $\frac{1}{2}$ per cent. is converted into the light which it has been our object to produce.

This small result obtained in return for so much coal burned is most unsatisfactory, but how are matters to be bettered, and from whence is improvement to come?

It is evident that for the cheaper production of light by means of the incandescent lamp we must look to improvement in the lamp itself, for it is the most inefficient member of the system with which we have to deal, and since its introduction but little appreciable advance has been made in its efficiency. The production of light by the arc gives a somewhat better return, the ratio of luminous to total radiation being between 5 per cent. and 15 per cent., and the useful return from the heat units in the coal burnt about 1 per cent.

When electrical energy is required for the production of power, owing to the high efficiency of the electric motor, which is between 90 and 95 per cent., according to size, a net return of nearly 10 per cent. is obtained, and in this case the greatest loss takes place in the steam engine.

Besides the study of the efficiency of engines, generators, lamps, and motors, there is in connection with our present generating stations an item amongst the expenses, which all who analyse the published returns well know varies between wide limits, and this is the cost of fuel per unit generated. It might possibly be thought that these large differences were chiefly due to the price per ton which has to be paid, but investigation will show that, apart from any question of price, the actual pounds of fuel burnt per unit sold or generated vary widely at different stations, even though the quality of the coal may not vary greatly and the load factor may be very similar.

The type and size of engine, the class of boiler, the load factor, and the nature of the load, account for a great portion of this difference,

but it seems more than probable that there is, in many instances, a large personal element involved.

Electrical generating stations for lighting and traction have for some time been laid down on lines which have varied but little. There is, however, a great development before us. Large power-stations are about to be erected in various parts of the country to supply power over large areas, and many of the larger towns are building, or are about to build, very large generating stations. All those connected with these undertakings are naturally only too ready to take advantage of any new development, improvement, or invention which may assist to further economies. Are any such opportunities offered to us? Is there any probability of the present reciprocating steam engine being superseded, or can we look for improvement in the incandescent lamp, which, owing to its present low efficiency, is the most unsatisfactory member of our lighting system?

With regard to the former, two types of engines are now forcing themselves upon our notice. They are the steam turbine and the gas engine.

The steam turbine, in the able hands of its inventor, is now reaching a degree of perfection when it can no longer be neglected, for it is not only becoming the rival of, but for many purposes is actually threatening to supersede, the reciprocating engine. An engine in which the moving parts are reduced to the minimum cannot fail to be attractive, and in the turbine, valves, eccentrics, and reciprocating parts are entirely absent. The economies which have been effected in the steam consumption of the turbine are due to a variety of improvements, but to a large extent to the advances which have been made in connection with it when running condensing. The design of the turbine constitutes it a multiple-expansion engine, in which the steam can be expanded one hundred- or even two hundred-fold, as compared with eight- to sixteen-fold in the compound or triple-expansion reciprocating engine. To this exceptional ratio of expansion the economy of the engine is to a large extent due, and as the expansion extends over nearly the whole range between the boiler pressure and that in the condenser, the effect of a good vacuum is most important, and for every additional inch of vacuum above 25 to 26 a saving of approximately 5 per cent. is obtained. In the turbine there is no initial condensation, and therefore greater gain by a good vacuum than in the reciprocating engine. In the latter type of engine a function of good vacuum is a corresponding increase of size of the engine so as to cope with the greater volume of steam, but this is not so in the turbine, and on this account, in the turbine, steam can be expanded to a limit which mechanical considerations render impermissible in the reciprocating engine. In the average reciprocating engine much loss is caused year in and year out by leaky slide valves, and great loss is due to alternate contact of the inside of the cylinder walls with cold exhaust and hot steam; but in turbines, as the flow is always in one direction, there are no periodic fluctuations, and therefore none of the above loss. Besides the excellent results as regards steam consumption in the turbine, it claims other advantages of considerable importance. The first cost of the combined plant is

appreciably reduced, the necessary buildings are much smaller, and the foundations inexpensive. No internal lubrication is necessary—the saving on this account is considerable—and the condensed steam can be returned to the boiler uncontaminated by oil, and without the necessity for oil filters.

The second type of engine, viz., that using gas as the motive power, has comparatively recently, owing to the greatly increased size in which it can now be built, and the production by various processes of cheap gas, won for itself a very high position, and one which is fully justified by its performances, and it has established its claim as a competitor of the best and largest steam engines.

The four strokes per cycle single-acting engine is that which in the past has been commercially the most successful, but as the demand for engines of larger and larger size has arisen, the disadvantage of only utilising one stroke in every four for the generation of power, and the necessity for two or even four cylinders for engines of no very great power is tending rather to the adoption of one impulse per revolution, or even one impulse per stroke.

Records exist in great quantity of gas engine performances, both for the older and more modern types, but it is unfortunate that confusion should be so often caused in their study by the employment of units based on different temperature scales and weights. Thermal efficiencies are also calculated in two different manners, based either upon the higher or the lower value of the gas, and by the existence of three determinations of calorific value, and two methods of calculating the thermal efficiency, the performance of an engine may be presented to us in any of six ways. This in an outrage upon our time and patience, more especially when one has frequently to search through a whole book or paper to discover the units upon which the results are based.

So long as gas engines were run upon town gas their field of operations was limited to comparatively small powers. But as the size of engines increases, the efficiency of the steam engine rapidly improves, while for the gas engine it remains more nearly constant; consequently the utilisation of high-priced illuminating gas does not admit of economical working except for small powers. To enable gas engines to compete with steam for the generation of power on a large scale, a cheap and reliable gas is essential, and for many years inventors have been working on this most interesting and important problem. Apart from the question of producers, designed especially for the manufacture of power gas, there are sources of supply which, when available and turned to account, yield exceedingly valuable results, and the utilisation of the gases from blast furnaces and coke ovens—the great portion of which has up to the present been allowed to go to waste—is a problem of the very greatest importance.

Excluding illuminating gas, which is too expensive for use in large gas engines, natural gas, blast furnace and coke oven gases, which are only occasionally available, three kinds of gas remain, which are named respectively producer, water, and power gas.

Producer gas is generated by forcing a current of air through

glowing coal. Water gas is produced by passing steam through fuel which has been raised to incandescence by first passing a current of air through it. The production of power gas is a combination of the two processes, in which steam and air are admitted simultaneously, and though the resultant gas is poorer in quality than water gas it is richer than producer gas, and the process has the great advantage of being a continuous one.

Power gas was, during the early years of its manufacture, made from anthracite or coke, and excellent results have been obtained, by which a horse-power-hour is produced for about 1 lb. of coal, but lately a process has been designed which enables the cheapest bituminous coal and slack to be used and at the same time the ammonia to be recovered as sulphate of ammonia. It is hardly to be wondered at that this great advance in the economical production of gas has brought the question of the utilisation of gas engines for the production of power on a large scale into great prominence.

The relative working costs of gas- and steam-driven plants are dependent upon the quality and cost of fuel which the type of producer requires, and the cost of coal for the steam plant.

Briefly comparing a 400-H.P. steam plant with a gas plant of equal power (the latter utilising gas manufactured from anthracite), we find that a 400-H.P. compound steam engine, condensing, including boilers, boiler-house and chimney, would involve a capital outlay of approximately £5,900. When working this plant for 3,000 hours per annum, and taking the cost of coal at 10s. per ton, the total yearly cost, including depreciation and interest on capital, would be £1,575. This gives a cost per H.P. per hour of 0·325 pence.

Considering this against a gas engine, producer, and building, the total capital outlay for the plant for the utilisation of anthracite would be £4,500, and, taking the anthracite at 23s. per ton, the working expenses would be £1,475, or 0·3 pence per H.P. hour.

These figures relate to a plant in which expensive fuel is used in the producer, and when considering the cost per H.P.-hour it must be borne in mind that it is assumed the plants are running for ten hours per day on full load.

With respect to producers for the production of gas from bituminous slack, the cheaper fuel gives results which show a considerable economy when gas plants of even 500 H.P. are compared with steam, and without taking into account the question of ammonia recovery. But when the power rises to 3,000 H.P., or thereabouts, and it becomes economically advantageous to recover the ammonia, the value of this bye-product reduces the nett cost of the gas to such a figure that, with coal delivered at 8s. a ton, the nett cost of fuel does not exceed one-twentieth of a penny per H.P.-hour. Such a result is one which points to the certainty of the adoption of the gas engine for all large power plants.

Besides the reduction of coal consumption by the aid of rotary steam engines or of gas engines, there is the possibility of reducing the cost per unit by improving the load factor. A large generating station, with a tramway and power load may have a factor approxi-

mating to 20 per cent. If this could be increased to 50 per cent., costs would fall by practically one-half. Storage batteries are the only known means at our disposal for effecting an immediate change of this magnitude; large first-cost and the maintenance charges alone stand in the way of their immediate adoption upon an enormous scale. We are, in fact, waiting for the ideal storage battery. The destruction of storage batteries is due to the continual expansion and contraction. A cell with a life greatly in excess of anything yet produced is no impossibility. Whether the iron, nickel-oxide battery, of which we have heard, is to solve the problem of long life, or whether iron is to replace lead, I do not know; but iron is the cheapest of metals, and, weight for weight, should yield a watt-hour output about the same as zinc, and many times greater than lead, and if the initial difficulties have been overcome this new departure in batteries will be of the first importance. But it is well to note that a great length of life is not all that is required, the first cost being as important a factor, for the interest on any additional outlay must be charged against any saving effected in yearly depreciation; and, if the cost of the battery is increased, in order that the yearly charges shall remain constant, the life must increase as the square of the cost. Apart, however, from the use of batteries merely for the purpose of storage, there is an immense field for their employment as regulators in large power-stations.

Touching upon the question of the supply of electricity in bulk for power and other purposes, this is a subject upon which a war of argument has been waged, and the financial success of such undertakings has been questioned. We may, however, leave this great question to decide itself upon its merits, for several of the power companies have already started operations. The power companies have been excluded from giving customers a supply within certain town areas, with the object of protecting the municipalities from competition, and although the towns are at liberty to take a supply, or give permission to supply, they as a rule do not at present look with favour upon these gentlemen with roving commissions. Still, the effect of the companies, carrying on operations outside their gates, will be felt, for low charges for power will tend to attract small manufacturing firms to districts where rates are low and land is cheap.

I have given some consideration to the question of the supply of energy by power companies for the purpose of lighting small districts, and have also worked out the savings that would be effected and the extra expenses that would be entailed by putting in batteries of sufficient size to increase the load factors from 9 per cent. to 20 per cent., and the result of my investigations goes to show that the prices which would have to be charged compare most favourably with those charged by small companies having outputs similar to those I have assumed. But the true object of the power companies is the supply of energy for *power*, and for success upon a large scale all costs must be cut down to the lowest possible figure. Hence such companies are bound to give, as I have said before, consideration to the steam turbine, the gas engine, etc. The cost of the electric *light* could also be reduced by improvements in the lamp itself. At the present time the efficiency

of the lamp is such that the hourly cost of current greatly exceeds the hourly cost of the lamp, for, taking the cost of a 60-watt lamp at 1s. and its useful life at 1,000 hours, we find that at 4d. per unit the hourly cost of current amounts to twenty times the hourly cost of the lamp. This great difference between the two charges indicates that the lamp should, on commercial considerations, be called upon to do more work with a smaller expenditure of power, even if thereby its life were shortened. Many attempts have, of course, been made to produce a substance capable of being run at a higher temperature than carbon, and there is no reason why we should not look forward to an efficiency which would at any rate halve, or even quarter, the present cost of lighting. The mercury lamp may indicate the type of the future, but at present the quality of its light is not such as would recommend its adoption.

And now to what extent are our home firms in a position to take advantage of home and colonial demand. I am convinced that we are in every way able to hold our own in the competition, but we must not fall into the dangerous error of hiding from ourselves the many excellent features in the machinery of our foreign rivals. Looking back upon the steady and continual progress which has been made, and considering the great opportunities that are still open for improvements in the various branches of electrical engineering, the many applications of electricity which are only yet partially developed, and its great future in connection with power-distribution and electro-chemistry, one cannot help feeling with some degree of confidence that the progress of the present century will equal, if not surpass, that of the last.

LEEDS LOCAL SECTION.

INAUGURAL ADDRESS OF CHAIRMAN,

By Mr. HAROLD DICKINSON, Member.

(*ABSTRACT.*)

(*Address delivered February 19th, 1903.*)

In electing me your chairman for the first year of the existence of the Leeds Section of the Institution of Electrical Engineers, you have conferred on me an honour of which I am justly proud, and for which I thank you.

In the earlier part of my address I propose briefly to rehearse the objects and advantages of the Institution, and with regard to the rest of my remarks I have decided, after some thought, to leave all technical matter to be dealt with in papers specially devoted to specific subjects and to seek to lay before you the commercial and educational problems with which, sooner or later, we shall have to deal. This I do in no dogmatic spirit, but rather in the hope that, by pointing out what I conceive to be imperial issues, an avenue is opened for their consideration and discussion.

The Institution of Electrical Engineers was founded in 1871 under the title of the Society of Telegraph Engineers. It is the oldest and largest Institution of electrical engineers in the world. The Institution has not only grown rapidly in membership, but it has grown in its utility. Local Sections have been formed at home and abroad. *Science Abstracts* have been circulated. Visits have been paid to foreign countries and capitals—to Switzerland in 1899, to Paris in 1900, to Berlin in 1901, and one will be paid to Italy this year, and another to America next year. The Institution has also exercised its influence in regard to Board of Trade Regulations, Factory Acts, and so forth.

I have indicated some of the lines on which the Institution has moved in the past, but there are other duties that will be expected of it in the future. The competition from foreign nations now being experienced in the electrical industry necessitates the careful attention of the Institution to all the problems relating to the progress of the industry, which I hope soon to see having serious consideration, such as questions of the management and conditions of workshops, conditions of labour, education and fiscal conditions. These questions necessarily cannot be discussed by an Institution of this kind with any view to interference, but purely so that the best methods may be brought to the notice of the manufacturers themselves and the representatives of labour, education, and the public at large. Then the Institution may, through its influence with the Colonies, be able to promote the interest of the industry by making known to its Local Sections all that is going on at

home and abroad. Further, the conviction I believe the Colonies have that the electrical industry at home is in a worse state than actually is the case, can easily be corrected through their own Sections.

As to the origin of our Local Section, I may remind you that it was some nineteen years ago that the first efforts were made to form an Electrical Engineering Society in Yorkshire. The movement, however, fell through. Through the instrumentality of our Hon. Sec., Mr. G. R. Blackburn, a local society has now become an accomplished fact by the formation of the Leeds Section.

I should like to point out, now the Section is in existence, that the responsibility of members does not end with the payment of the annual subscription, and that, in order to make the Section a success, it is necessary each member should take a keen interest in the work. I find that the membership of the various Local Sections is as follows: Manchester 445, Leeds 181, Birmingham 180, Glasgow 175, Newcastle 140, Dublin 65. It will be seen, therefore, that with regard to membership, as compared with other Local Sections, we are very well off, and it only remains for the members to put in a little of the enthusiasm they instil into their profession to make this Section one of which the parent Institution and the other sections will be proud.

Before coming to the immediate subject of the second part of my address, I should like to call your attention to the phenomenal progress which the industry in which we are all interested has made during the last thirty years. In the early days Telegraphy was its mainstay, then came Telephony, then Lighting, and then Traction, in which there is now £60,000,000 of capital invested. In regard to lighting, the enlargement of the business has enabled the cost of production to be reduced, and we may anticipate further reductions in the near future by reason of the improvement in the load-factors due to a more diversified type of user. The price at which electrical energy can even now be sold is such as to place it within the reach of all classes.

One great reason why there is not a much greater increase is, I think, the initial cost of wiring. Any steps taken to reduce this cost must tend to the benefit of the business and lead to an increased use of electric light as an illuminant.

We have all recently heard a great deal about the various power schemes that have been formulated throughout the country. It seems to have been assumed by many people that because a scheme is designated a power scheme it possesses some merit which will enable power to be supplied at very low cost, but the principles which go towards the production of energy at low cost are apparently forgotten. Unless a power scheme has a good load factor it seems hopeless to expect low costs, yet in many of these cases the areas are immense and the districts very scattered, which involve very heavy distribution costs. I do not wish to say one word to discourage any scheme which may benefit the industry, but I consider that, before the public are invited to subscribe money for the development of some of the schemes proposed, the facts should be very carefully weighed in the light of our present experience of the factors which govern the cheap production of power, for, if a number of these schemes are unsuccess-

ful, it will tend to shake the confidence of investors and thereby cause a serious check to the industry.

What has already been stated shows very briefly how the industry has advanced, and its continued advancement may be forecast when we consider the number of new schemes for the future.

Our Position to meet Competition.

But, gentlemen, the consideration we have just given to the development and prospects of the industry at once suggests the question, "To what extent are we equipped for meeting the future, electrically and generally?"

It will be admitted that commerce plays a very important part in deciding the position that a country occupies among the nations of the world, and, true as this is of our day, how much more so is it of the future? We must all appreciate this, and it is therefore incumbent on us as a nation to study commerce and all things that tend to enlarge and foster it. There are, of course, many avenues through which we may study it, and this brings me to the crux of my address, and, conscious as I am of my own limitations, I only deal with the subject because I feel that the position of commerce generally, and the electrical industry in particular, in the United Kingdom is not on the sound basis we should all like to see it. The question before us is of vital importance both to the producer and the user of electrical apparatus. The magnitude of the problem is obvious, and I fully appreciate the vast knowledge essential in order to arrive at a correct decision as well as my own lack of that wide experience necessary for the formation of any reliable opinion. But as to the *lines* of the question I am fully convinced, and I content myself rather with suggesting those lines than with the expression of any very definite opinion thereon. So serious is this problem, not only to our industry, but to commerce itself, that I am sure every one who has the welfare of the empire at heart will feel that, whatever one's limitations, one is quite justified in raising one's humble voice to swell the chorus now being raised that serious, studious, and practical application may be given to the issue before us.

There can be little doubt that, till quite recently, British capitalists and manufacturers have dozed. The commercial habits of their early days have been allowed to be the only habits that could attach to business life. Precedent has been followed instead of new precedents being established. Indeed, I suggest that precedent should be, comparatively speaking, a dead word, for a new precedent is scarcely established before the environment of commercial life renders it antiquated. A perpetual study should be given to the ever-changing conditions of commerce, and business should be continuously adjusted to these conditions. Fortunately, the commercial instincts of our day have responded to the uneasiness occasioned by the wonderful advances of our commercial rivals, and the last few years have been spent in good work whose fruit will assuredly be seen.

But it will be obvious that the question "To what extent are we

equipped for meeting the future?" is not merely a question of our day. It is one for all time. Each generation must ask itself that question. Having asked it for our own day, let us proceed to examine it. It seems to me the question must be examined under at least the following four heads: (*a*) Foresight, (*b*) Management, (*c*) Education, (*d*) Fiscal Conditions.

Foresight.—The consideration of foresight may be dismissed in a few words. One instance of the want of foresight of our electrical manufacturers may be seen in their neglect to lay themselves out some years ago to meet the demand for the larger units required for central stations, with the result that so many of the largest sets were supplied by foreign firms. It is always easy to speak after events have passed, but that this demand would arise for larger units was so absolutely certain and so perfectly obvious to those who considered the subject that it is astonishing to me that manufacturers should have allowed themselves to be in the invidious position of seeing orders, which ought to have been theirs, going out of the country.

In this connection I appeal to our moneyed classes to realise more fully the dignity of commerce, to sink their money in ways that, if they do not yield immediate prospects, will certainly show handsome future returns. It is to these men we must look for assistance in the opening up of new markets. It is of them we demand that instead of buying up landed estates that yield but little either now or hereafter, they will invest in that which will ultimately provide them an ever-increasing yield and the nation with a hard-working, intelligent, commercial community.

Management.—In considering this question we must do so in comparison with our competitors abroad. In the electrical industry it is, I say, a serious reflection on our manufacturers of electrical plant that the bulk of the orders for the largest schemes have gone to foreign firms, or at any rate to firms of foreign origin. It gives much food for reflection that to-day the purely English electrical firms, with perhaps but one exception, are not in a position to take one of these large contracts in competition with the large American or Continental firms, for the simple reason that the English companies are too small. I do not say that they could not execute the work from an engineering point of view. I think they could, and certainly as well as (possibly better than) the foreign firms, but I say that for financial reasons such contracts are prohibitive to them at present, the risk with their comparatively small capital being too great unless they could get the contracts at their own prices, which must be liberal. They dare not take such a competitive contract, for the reason that it would mean that their works would be run almost entirely for one job, and in case of any miscalculation they might be put into a very awkward position. It is evident that our manufacturers are now progressing, but I am afraid it must be admitted that it is not so much due to their desire to obtain the best results, but rather to sheer necessity.

With regard to the question of labour, I think our manufacturers must, in their own interests, and in the larger interests of the nation, study this question seriously. I know that blame is laid at the door of

the working man for restricted output, and often do we hear the men criticised in this respect; but is it just? Is the blame all on one side? I say emphatically, No. I believe the cause of restricted output is due to the system of payments generally in vogue. If you wish to get the greatest output you must pay for it. This, it seems to me, can only be done by paying on a liberal scale on the bonus or premium system, or some other system which will give an inducement to exert best endeavours. If this practice were more general in England we should see more of the close attention and the steady and consistent application to the work on hand that is so marked in up-to-date workshops. The greater security the manufacturer can show for the future maintenance of the higher wage earning facility this scheme affords, the greater will be the chance of the system becoming general, which will be to the permanent advantage both of the manufacturer and the artisan. It must be understood, of course, that in advocating this attempt to obtain increased output, I am not advocating in any way any lowering of the standard of quality of goods produced.

In addition to this, the workman should be induced by every means to use his brains to suggest any new process or tool to facilitate greater output, and to do this it will be necessary to compensate him for his skill where it is found to be beneficial. I have often heard it said that the British working man has no brains. I do not believe it, and I sympathise with what he has said, by his actions, that he is not prepared to give the manufacturers "something for nothing." If he has brains he is capable of being influenced, and it is the duty of the manufacturer to see that he is properly influenced, and this can be most readily done by making it worth his while to try.

The last point I would mention under this heading is that of advertisement. There can be no doubt that orders have gone to at least one of our rivals because of what I will term his arts in advertising. These are not confined to the orthodox announcement in a trade journal, nor to the apparently inspired leaderettes in the daily press and the monthly magazine, but to his assiduous and ofttimes daring approach to possible users by careful and attractively penned letters, and by the ingenious ways—I was going to say bluff—of his representatives. I think we underdo advertisement as much as this particular rival overdoes it, and suggest our manufacturers give more heed to the subject. The moral I wish to point is that the British manufacturer has hitherto been too modest in advertising, and that the time has arrived when the excellence of his productions and his stereotyped form of trade journal announcement shall not be his only means of communicating his existence to the world. I suggest he give some study to the subject of judicious advertisement and seize every opportunity of acquainting possible buyers and the general public, through the medium of the daily press as well as the trade journals, with what he has done and is doing.

Education.—On this subject let me request you all to read anew Professor Perry's inaugural address of 1900. Whilst I emphatically disagree (not from any strained patriotism, but from reading and observation) with the Professor's inference that British electrical

engineers are behind those of America or the Continent in skill or aptitude, the re-perusal of his brilliant and practical "straight talk" is a tonic we should all take periodically. But, as I pointed out in my letter which appeared in the *Electrical Times* of the 20th December, 1900, if the British engineers' theory is faulty and incomplete, the methods adopted in our colleges and institutions must be faulty and incomplete. Since then there has been a practical advance in general commercial education, but the curricula followed are mainly on foreign lines. I assert that we should be in the van of technical educational progress, not followers merely. Those in charge of this important department of our national activities should certainly have associated with them representatives of every branch of engineering, and they should formulate a British curriculum. The value of constant and intimate association between technical schools and manufacturers cannot be overrated. The need for such co-operation is growing, and, as the benefits of the secondary schools go to the manufacturers, I am quite sure co-operation will result in manufacturers helping the schools with funds and plant.

Fiscal Conditions.—The question of our fiscal conditions is one that, as I have already stated, I am not prepared to dogmatise upon. On the one hand, keen competition and the necessity for tackling big jobs, which leads to amalgamation and combination, often ends in trust abuses, whilst, on the other, a mote of necessary protection may lead to a beam of abuse. Yet there is no doubt the tariffs of foreign nations are becoming vexatious and require much study.

As regards our specific business, I have been thinking the matter over and have come to the conclusion that there is, in some measure, a degree of excuse for the holding back of our wealthier manufacturers and financiers from erecting big works and laying out extensive plant when there is always the bogey over their heads that empires, which have protected their internal trades by walls of tariffs, have free access to sell over here their surplus at less than cost price, or undertake big jobs at practically cost price, the which keeps their plant fully occupied and has an obvious effect on their trading. The electrical work of to-day and of the future renders big works absolutely essential. Our foreign competitors when erecting such can always feel they definitely command their home markets and can compete on practically equal terms in ours. Have our manufacturers always to endure this increasing restriction abroad and still be weighted by not even having their home markets secured?

I fully appreciate and most earnestly sympathise with our British artisan, and think everything should be done that can be done to elevate and help him. But the question naturally arises: "Is it not possible to cover the increased price of necessaries which might arise if we adopted some measure of protection by the extra work this country would obtain and the higher wages it might pay, and, at the same time, might not other possible grievances be foreseen and foreguarded by systems of bonus or profit sharing?" It may be that the welding together of the British Empire will largely reduce the poignancy of the question of free trade as it stands to-day, but that is a matter of very

considerable time, involving as it does the fiscal policies of young nations.

Under this head, too, the question arises as to whether our Government gives sufficient consideration to trade questions. We are agreed that we do not want too much Government interference. But I am heartily in accord with the movement now being mooted by eight Chambers of Commerce that the time has arrived when we should have a Minister of Commerce, whose duties should be initiative rather than administrative, whose time should be absorbed in finding openings for trade and advising on all matters concerning the conditions of trade abroad. In this direction invaluable work is being done by the Commercial Intelligence Department of the Board of Trade. But, good as is the work of this department, it only goes to prove the necessity of its having a separate existence. The administrative work of the Board of Trade is vast. What we need is some one who is free to initiate and who will be responsible for any neglect in this direction.

I hope I have made it quite clear that I advance neither the doctrine of free trade nor that of protection. What I do assert is that the question is a grave one, immediately demanding further study, and I plead that pressure be brought to bear on those in high places at once to collect and study the data necessary for arriving at a conclusion to lay before the nation.

In conclusion, let me assure you I am no pessimist. If we have not kept abreast of the times it has been for reasons that would perhaps largely have led to others becoming lax had they been in our place. The British manufacturer is a man with a level head and a lion's pluck, and he has awakened from his slumbers. The British workman is a good fellow. I tell you I have been all over the British Isles on the one hand, and on the other hand I have visited many big works in the principal towns of the United States, Germany, Austria, and elsewhere, and, whilst allowing for the disadvantages of flying visits, I did not go with my eyes shut, and I tell you that for solid good work we are unrivalled. To this good property we are soon to add the advantages of our new interest in Technical Education and the like, and if only employers will devote themselves to the earnest, strenuous study of inter-trade problems and can see their way to bring men to be paid on results—and in no mean spirit—the prospects of the old country in the future are as great as ever they have been in the past.

NEWCASTLE LOCAL SECTION.

EXPERIMENTS ON SYNCHRONOUS CONVERTERS.

By W. M. THORNTON, D.Sc., Member.

(Paper read at Meeting of Section, December 1, 1902.)

§ 1. The growth of large schemes for the electrical transmission of energy by high-tension alternating currents is probably the most remarkable feature in modern industrial development. The success of these schemes depends mainly on unfailing regularity of supply, and this again on the stability of the electromagnetic system of generators, line, and motors under all loads. Those responsible for these schemes make very cautious experiments, the cost of misadventure is too great, and the machines themselves are rarely available under all the conditions necessary for a complete study of their behaviour. I had the pleasure of making some observations of wave-forms on the synchronous motor system of the Wallsend scheme, and these suggested that a more detailed research into the working of the two synchronous converters in the college laboratory might add to our knowledge of the complex reactions within the armature of this and allied classes of machinery. The research is entirely experimental. There are so many variables that it is useless to attempt to construct a theory including all of them. Steinmetz and S. P. Thompson have given analyses of the ideal case in which the magnetism is distributed sinusoidally around the circumference of the armature. But though, as will be seen, the generated voltage wave-form at no load closely approximates to a sine curve, this can only be obtained by a magnetic distribution which is not sinusoidal. Kapp has considered the variation of output with relative breadth of pole, showing that within practical limits the output is less for the same armature heating when the poles are broader. In Table I., I quote his figures for two cases, and have calculated corresponding values for the machines used in these experiments, which are not specially-designed

TABLE I.

Type.	Phase displacement.	Sine distribution.	Pole breadth ÷ pole pitch.			
			$\frac{2}{3}$	$\frac{1}{2}$	·61	·88
Single-phase converter	$\cos\phi = 1$	85	88	95	83·6	85·7
	$= ·9$	78	81	88	70·5	75·8
	$= ·8$	69	73	80	62·3	67
	$= ·7$	60	63	70	54·1	57·2
Three-phase converter	$\cos\phi = ·1$	134	138	144	160	160
	$= ·9$	not calculated.	128	137	149	146
	$= ·8$		117	126	132	132

converters. The figures are percentages referred to the same machine working as a direct-current generator for equal armature heating in each case. In the last two columns are the values which might be expected from the two machines used calculated in the same way as Kapp's.

The alternating current, i, which heats the armature to the same degree as the direct, $i_{\prime\prime}$ is $i = \frac{\pi}{\sqrt{q}} i_{\prime\prime}$,* the values of q being given in Table VII., and from this relation the latter part of Table I. was obtained. The

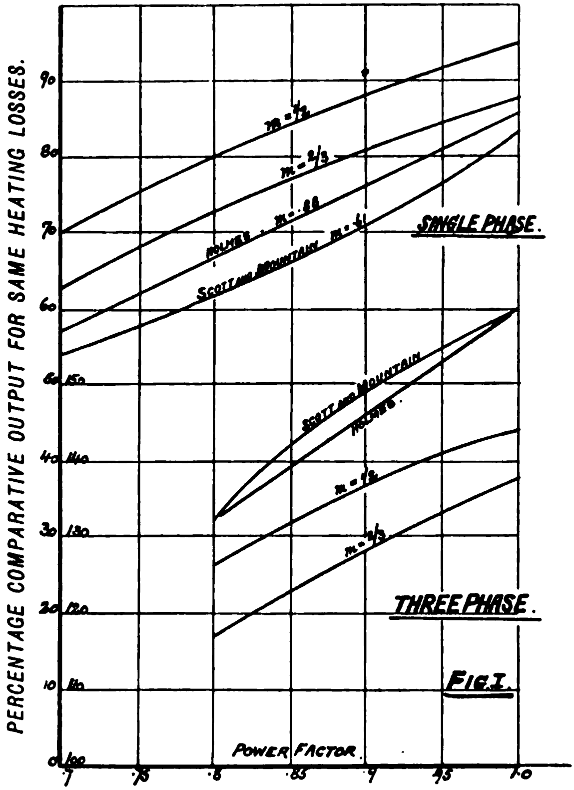


FIG. 1.

results are not total efficiencies. The watts lost in the field, friction, windage, and eddy currents are all omitted, but the results are instructive, as showing the variations in the principal source of loss of efficiency. The comparative values of Table I. are plotted in Fig. 1. Most of the curves show that the relation between power factor and efficiency is not linear, the curvature being generally upwards. The Scott and Mountain single-phase curve is, however, the reverse of this, and in both single and three-phase sets the armature heating is approximately

* Kapp, *Dynamos, Alternators, and Transformers*, p. 476.

in inverse proportion to the power factor. The meaning of the curves drooping towards the low power factor end is in these cases the loss of efficiency due to change of distribution of the current in the armature, and has nothing to do with the effect of the eddy currents in the poles.

§ 2. The object of the experiments was to find how the efficiency of the plant varied with load for all conditions of excitation, to find any

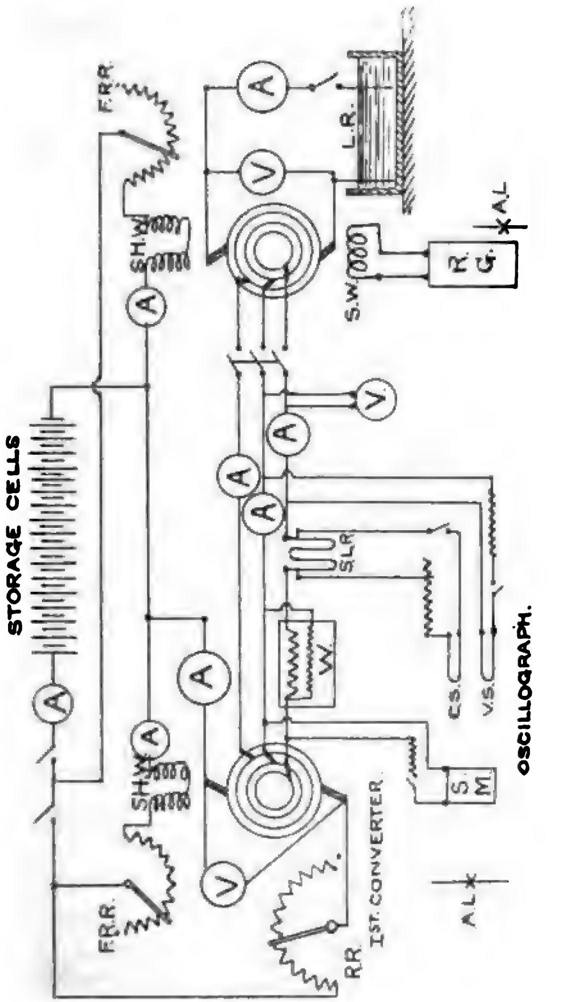


FIG. 2.—A, Ammeters; V, Voltmeters; W, Wattmeter; S H W, Shunt Winding; S W, Series Winding; R R, Regulating Resistance; F R R, Field Regulating Rheostats; R G, Recording Galvanometer; L R, Liquid Resistance; S L R, Standard Low Resistance; C S, Current Strip; V S, Volt Strip; S M, Synchronous Motor; A L, Arc Lamps.

discrepancies between the theoretical and observed losses, and to locate the causes which would give rise to them. At the same time, it was thought that records of the changes of wave shape might throw some light on the nature and magnitude of the armature reactions. The greatest difficulty in synchronous converter working being periodic

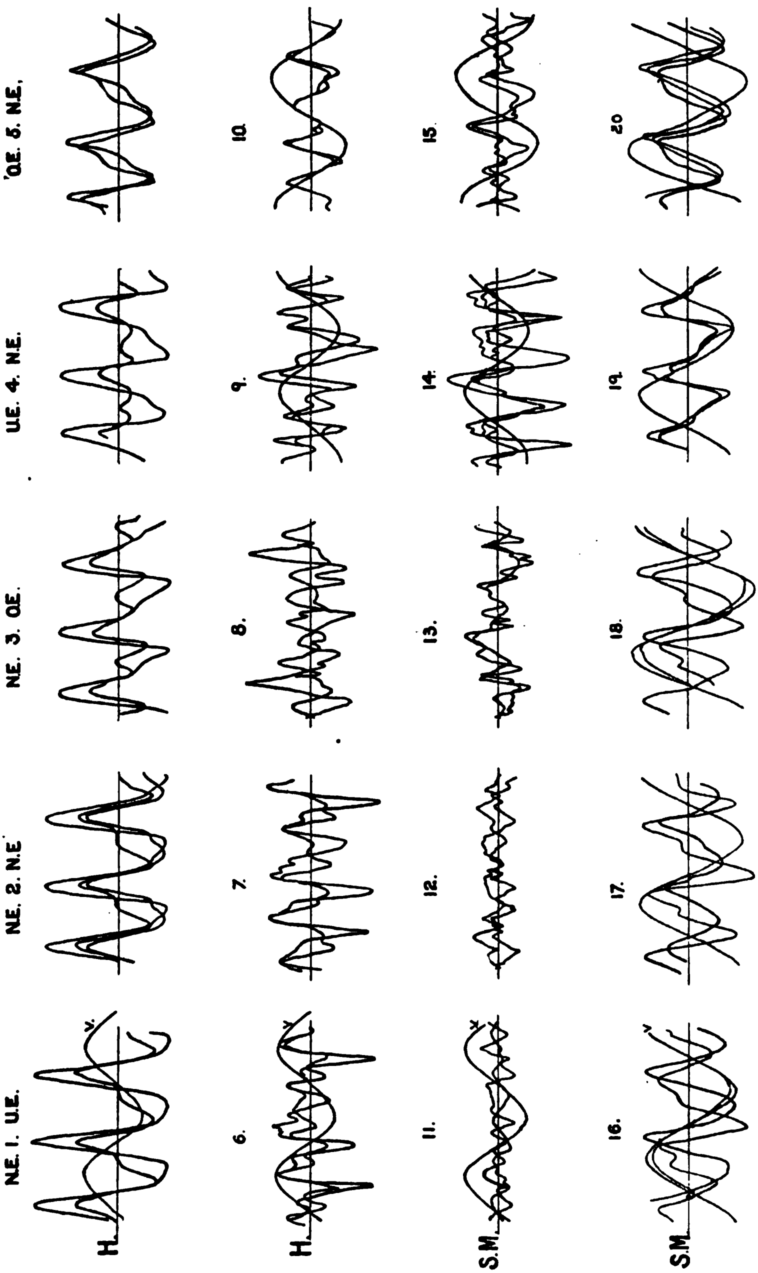


PLATE I.—Oscillations superposed on Magnetic Fields of Converters by Armature Reaction.

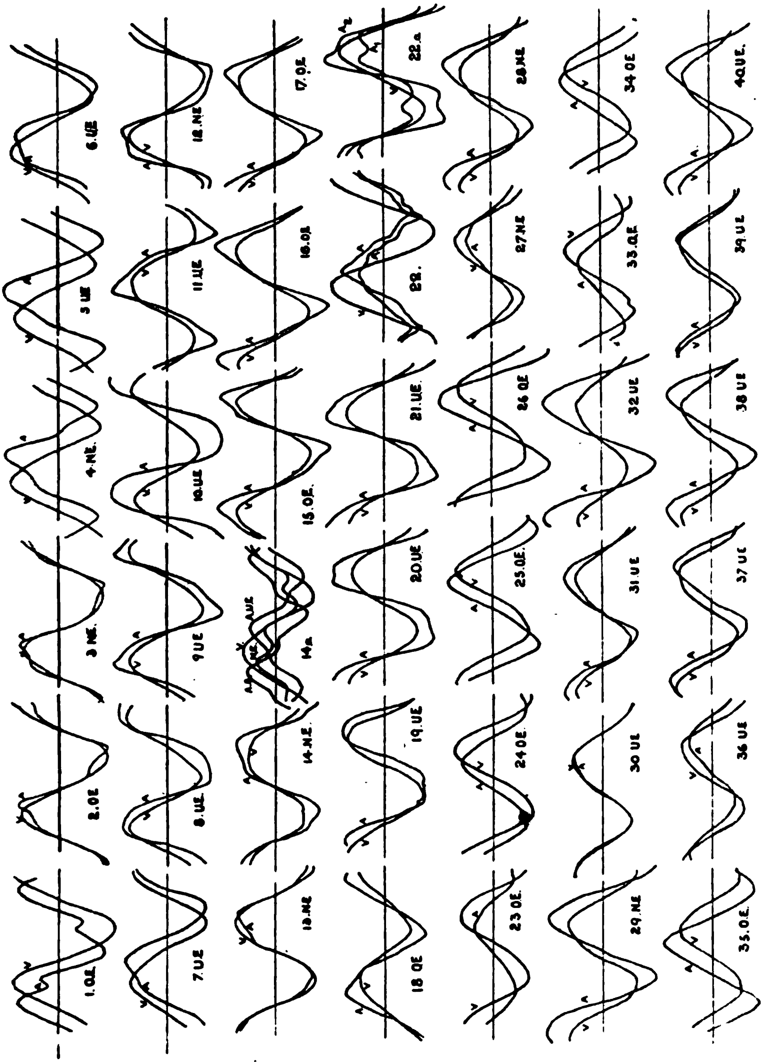


PLATE II. - Change of Wave Form and Phase with Excitation and Load in Synchronous Converters.

fluctuations started from irregular turning moments in the prime mover, the first machine was driven throughout from a set of storage cells. Fifty-two of these were used to drive a 9-kw. bipolar machine (Scott and Mountain), the armature of this being ring-wound and provided with slip-rings, so that single, two, or three-phase current could be taken and supplied to a 5-kw. machine (Holmes), also bipolar and ring-wound in the same way. From the second converter direct current was led through an adjustable liquid resistance. The field of each machine was separately excited from the same cells. A direct-

reading Siemens and Halske wattmeter was inserted in the line in series with a standard low resistance, from the terminals of which connections were made to one strip of a double oscillograph. The other strip was placed in series with a non-inductive resistance across the line terminals in turn. The resistance and capacity of the cables connecting the machines were always negligible. The general arrangement of the connections is shown in Fig. 2. There is, it will be seen, a double conversion of current, and one point of interest brought out by the experiment was that the heating losses of the system could, by varying the excitations, be moved from one machine to the other. The two

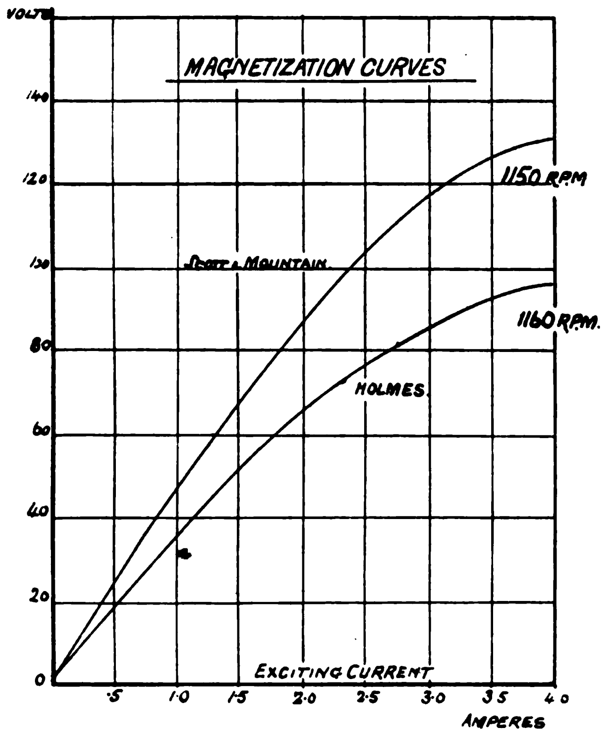


Fig. 3.

machines were run up together from rest coupled by the cables alone, and the load gradually thrown on. Throwing it on suddenly started violent phase swinging in the second converter, which measured in one case 50 deg. difference between the limits of the current wave positions, as shown by Curve 22, Plate II.* The highest frequency possible was 23 alternations a second. The first set of experiments was made to find the relation between total plant efficiency and power factor. The

* Greater swings might have been observed, but whenever the amplitude increased beyond the above limit, the oscillograph synchronous motor came out of step.

observations are given in the following tables, and the magnetisation curves of the machines in Fig. 3. From the latter an estimate of the saturation of the magnetic circuit may be formed. The reluctance of the Scott and Mountain at full excitation is *·00455*, and of the Holmes *·00527*, and the lengths of the air-gaps are *1·15cm.* and *1·06cm.* respectively.

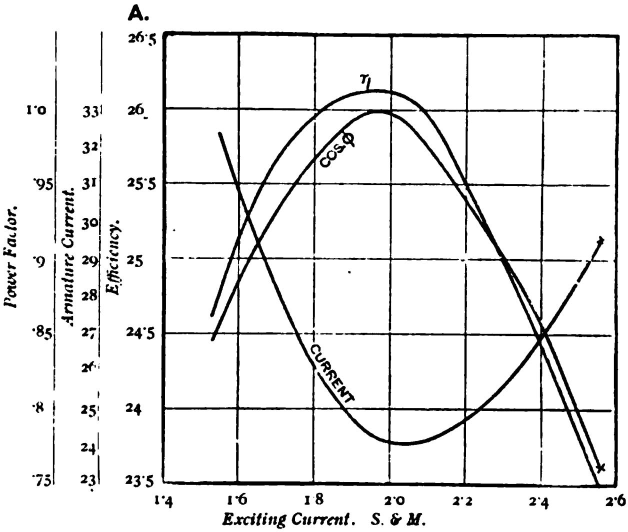


FIG. 4.

TABLE II. (FIG. 4).

Field of first converter varied. Motor field constant. Loss in motor field, 330 watts. Motor output kept as nearly as possible constant.

First converter input.				Motor input.					Motor output.		Efficiency
Volts	A.	F. C.	Speed.	F. C.	V.	A.	W.	Cos φ	V.	A.	%
70	28·5	1·55	1,000	3·7	45·5	32·3	1,125	·85	72	8·2	24·6
71	27·5	1·62	1,000	3·7	46·5	30	1,250	·90	72·4	8·3	25·3
72	26·3	1·70	990	3·7	47·0	28·2	1,225	·93	72·4	8·3	25·8
74	25	1·85	980	3·7	48·0	25·3	1,174	·97	72·4	8·2	26·0
75	24	1·98	950	3·7	48·2	24·1	1,165	·99	72	8·1	26·1
75·2	23·5	2·10	930	3·7	48·5	24·0	1,134	·97	70·6	8·2	26·1
74·5	24	2·12	900	3·7	47·8	25·25	1,150	·95	70	8·0	25·6
76	23	2·34	920	3·7	48·1	25·9	1,100	·89	69	8·0	24·7
76	22·5	2·55	930	3·7	48·0	29·3	1,074	·76	67	7·8	23·5

It will be seen that the maximum efficiency is reached a little before the minimum current.

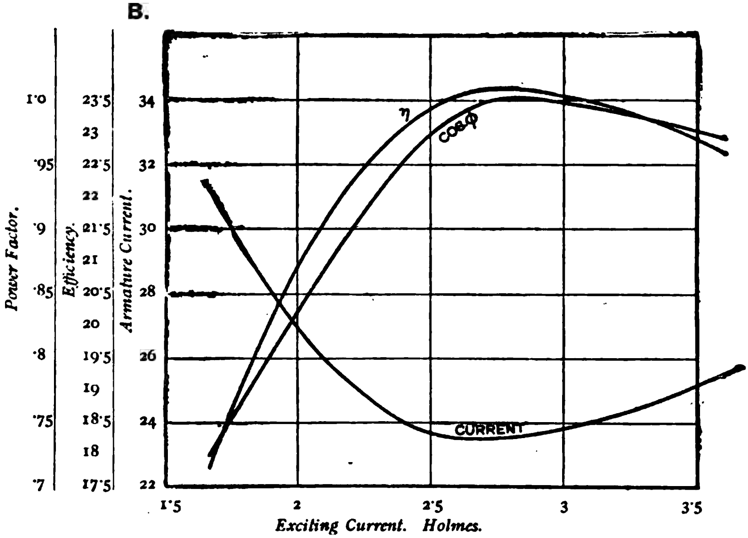


FIG. 5.

TABLE III. (FIG. 5).

Field of first converter constant. Motor field varied. Loss in first converter field, 116 watts. With the same input as in Table I., the output and efficiency are less.

First converter input.				Motor input.					Motor output.		Efficiency.
Volts.	A.	F. C.	Speed.	F. C.	V.	A,	W.	Cos ϕ	V.	A.	%
73	26·1	2	980	3·7	48·2	25·8	1,210	·97	72	7·4	22·6
74	25·8	2	990	3·29	48·5	24·5	1,180	·99	71·6	7·4	23·2
74·1	25·4	2	1,100	2·98	48·5	24	1,150	·99	70·6	7·3	23·6
74·2	25·2	2	1,010	2·7	48	23·5	1,129	1·0	69·7	7·1	22·9
75	25	2	1,030	2·5	48	23·7	1,104	·97	68·2	7·0	23·5
75·1	24·4	2	1,040	2·3	47·8	24·5	1,079	·92	67	7·0	22·5
75·1	24·4	2	1,060	2·17	47·2	25·3	1,069	·89	65·8	6·9	21·9
75·3	24·2	2	1,070	2·03	47	27	1,060	·83	64	6·7	21·0
75·8	24·1	2	1,080	1·93	46·9	27·8	1,044	·8	63	6·6	20·5
75·8	24·1	2	1,090	1·83	46·2	29	1,034	·77	62	6·3	19·2
75·8	24·1	2	1,090	1·75	46	30·1	1,024	·74	60·8	6·1	18·4
75·8	24·2	2	1,100	1·67	45·5	31·1	1,019	·74	59·8	6·0	17·8

C.

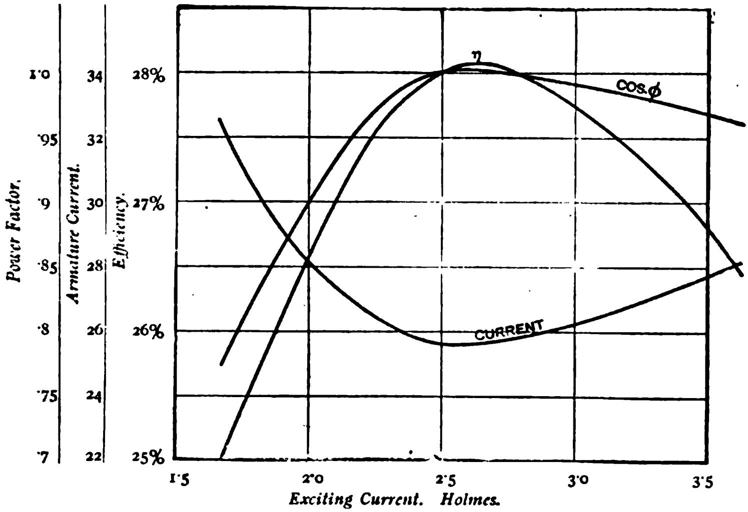


FIG. 6.

TABLE IV. (FIG. 6).

Field of first converter constant. Motor field varied. Current from motor kept constant.

First converter input.				Motor input.					Motor output.		Efficiency.
V.	A.	F. C.	Speed.	F. C.	V.	A.	W.	Cos φ	V.	A.	%
71·4	27·6	2	940	3·6	46·2	28	1,255	·96	69	9·1	26·4
71·4	27	2	950	3·2	46·4	27	1,234	·98	69	9·1	27·4
73	26	2	990	2·66	46·8	25·6	1,189	·99	67·2	9·1	28·0
73·2	25·8	2	1,000	2·28	46	26·2	1,160	·97	64·7	9·1	27·6
74	25·8	2	1,030	2·0	45·2	27·9	1,139	·90	61·5	9·1	26·4
74	25·6	2	1,040	1·8	44·8	30·0	1,109	·82	59·4	9·1	25·8
74	25·9	2	1,060	1·65	43·8	32·1	1,089	·77	57	9·1	24·9

The conclusion to be drawn from the above figures is that, as one would expect, the efficiency is greatest when the power factor is unity, *whichever field is varied*, and it is of interest to note the close relation between power factor and efficiency over a wide range of excitation while the output is maintained constant. Plotting the square of the

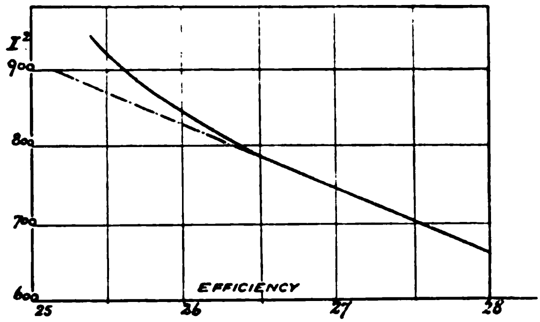


FIG. 7.

continuous armature current against efficiency (Fig. 7), it is found that, except at low magnetisations, they are proportional. At low excitations the effect of the large idle-current component is evident. In order to see whether the higher efficiency was maintained at all loads when the excitation was adjusted for the minimum armature current found above,

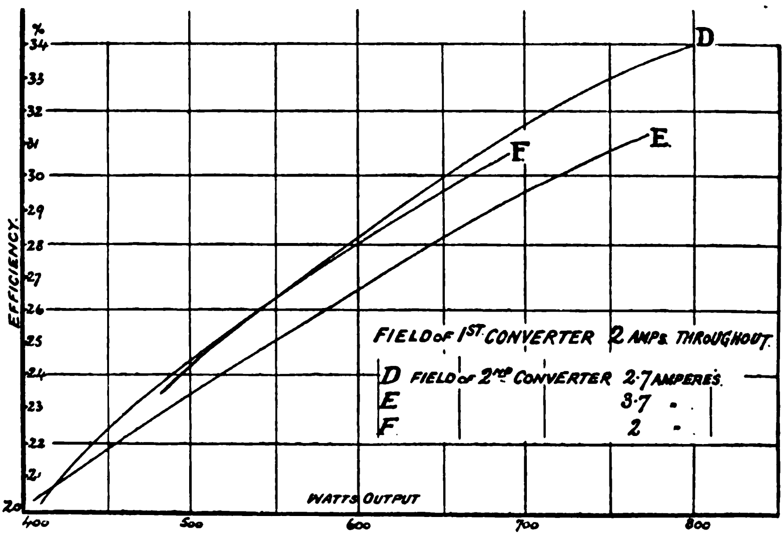


FIG. 8.

three more sets of readings were taken, shown in Fig. 8. The second converter fields were kept constant in each test while the load was varied. The improvement in efficiency obtained at light loads is seen to be maintained at the higher.

§ 3. The next experiment was a variation of the last, the machines being run under all conditions of excitation, and readings being taken of all the variables, including the wave-forms of the line current and voltage. The results with the calculated efficiencies are in Tables V. and VI., and Figs. 9 and 10 are plotted from these. The number of the curves refers to Plate II. The remarkable feature of the curves is their sudden droop at loads which, compared with the ordinary con-

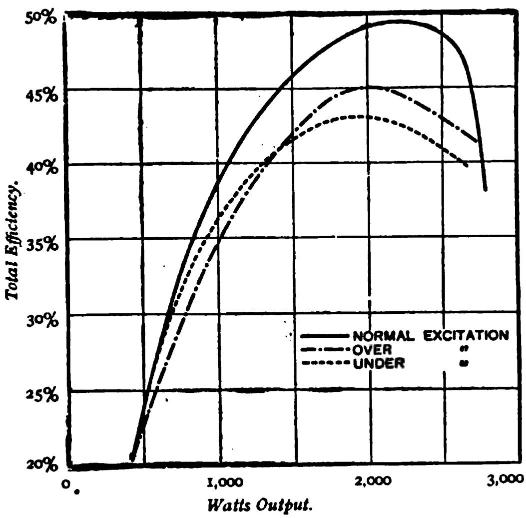


FIG. 9.—Single-Phase Converters.

tinuous-current output, are small. The reason for this appears more clearly when the machines are worked from the main generator, which being driven by a single-cylinder engine has an irregular turning moment. It was almost impossible to reach high loads without the second converter coming out of step, and the only way to obtain them was to over-excite the second machine and so reduce the eddy-current losses and magnetic-current fluctuations and gradually lower the excitation as the load was increased; even then the machine soon worked up a phase swing and came out of step. Fortunately, both armatures have considerable inductance, about ·002 henry, between the slip-rings, single-phase, and there were no ill effects beyond the racing of the first machine. This was the first intimation, as a rule, that the second had broken step, and it was always necessary to keep some one by the main switch of the first machine to break the current before the armature had accelerated to destruction. The advantage of normal excitation is most marked at the higher loads in both Figs. 9 and 10.

TABLE V. (FIG. 9).

Single-Phase Converters. Variation of Load with excitation constant.

Field Currents: First Machine, 2 Amperes; Second, 1·93.
(Second, Under-excited.)

No. of curve.	First Converter input.			Second Converter input.				Second Converter output.			Armature Efficiencies %.		
	V_c	A_c	W	V_a	A_a	W	Cos ϕ	V_c	A_c	W	1st c.	2nd c.	Total.
7	73	31	2260	46·4	44·2	1400	·68	53	13·4	710	62	50·7	28·7
	72·2	40	2890	46·4	51	1976	·83	52	22·7	1180	68·7	59·8	38·3
8	75·5	50·5	4150	43·6	.63	2640	·96	55	32·2	1780	69·5	67·5	44
	71	62	4400	40	74	2948	·99	50	39	1950	67	66	42·2
9	80	71	5680	45	84·5	3768	·99	56	44	2494	66·5	65·7	42·0
10	69·2	40	2768	42	48·2	1864	·92	54	22·5	1215	67·4	65	41·0
11	77	81	6240	41·2	96	3944	1·0	52	50	2600	63·2	66	40·5

Field Currents: First Machine, 2 Amperes; Second, 2·72.
(Second, Normal.)

12	73	36	2630	46·6	40	1840	1·0	68	18·75	1275	70	69·3	43·7
	74	49	3620	46	57	2620	1·0	67	28·75	1925	71·2	73·5	49
13	80·5	61	4900	49·6	70	3464	1·0	72	35·5	2550	70·7	73·6	49
14	72·5	100	7250	36	120	4348	1·0	52	46·5	2880	60	66·4	38

Field Current: First Machine, 2 Amperes; Second, 3·29.
(Second, Over-excited.)

15	71	40	2840	46	44	2000	1·0	68·7	18·75	1275	70·2	63·75	39·5
	75	49	3660	47	56	2636	1·0	70·5	25·7	1820	71·7	69	45
16	78	72	5616	46·5	84	3856	·99	70	36·5	2560	68·5	69·5	42·5
17	75	80	6000	43·2	95	4008	·98	65	38·5	2500	68	61·3	39·5

Field Currents: First Machine, 1·6 Amperes; Second, 2·7.
(First, Under-excited.)

	56	40	2240	44	45	1500	·76	56·1	15·7	885	67	59	36·0
18	50	44	2200	32	50	1500	·94	50·5	17·1	865	68·2	57·6	36·0

Field Currents: First Machine, 3·1 Amperes; Second, 2·7.
(First, Over-excited.)

19	68·5	33	2260	42	47	1480	·75	56·6	15·5	875	65·5	59·7	32·5
	76	45·5	3460	46	57	2400	·92	61	27·5	1675	69·5	70	42·8
20	71	57·5	4080	40·5	70	2860	1·0	52·2	38·5	2010	70	68	44·5
21	77	72	5540	43	88	3880	1·0	55	50	2750	70	71	46·0

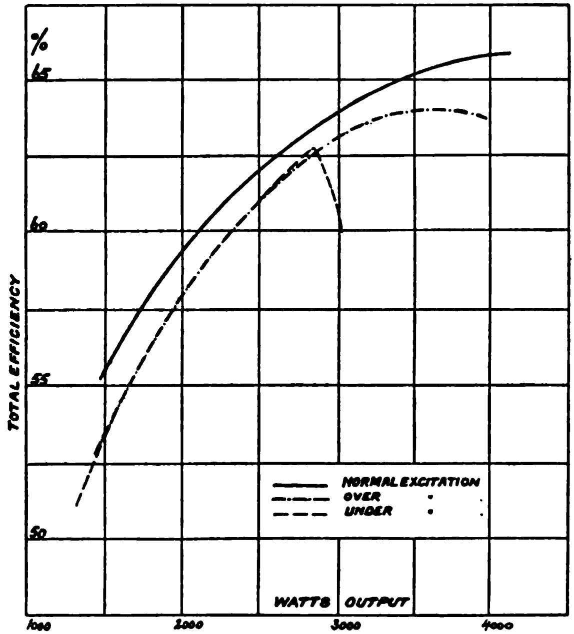


FIG. 10.—Three-Phase Converters.

TABLE VI. (FIG. 10).—*Three-Phase Converters.*

Field Currents: First Converter, 1·9 Amperes; Second, 3·62.
(Second, Over-excited.)

No. of curve.	First Converter input.			Second Converter input.				Second Converter output.			Armature Efficiencies.		
	V_c	A_c	W	V_a	A_a	W	Cos ϕ	V_c	A_c	W	1st c.	2nd c.	Total.
23	75	36	2700	44	23	1794	·75	76	19·8	1500	66·5	83·6	55
	79	44	3470	45·2	33	2480	·74	78	27	2106	71·4	85	60·5
24	85	54·5	4630	50	39	3352	·75	84	34·75	2920	72·5	87·2	63
25	81·5	69	5620	46	53	4122	·75	77	47·5	3660	73·3	88·7	65
26	77	82·5	6350	40·6	66	4650	·75	71	58·5	4160	73·5	89·5	65·5
Field Currents: First Converter, 1·9 Amperes; Second, 2·4. (Second, Slightly Under-excited.)													
27	75	37·5	2815	43·2	27	2472	1·0	74	20	1480	88	60	52·5
	70	46	3220	39	35·3	2480	·98	66	28	1848	77	74·5	57
28	75·5	43·5	4050	42	40	2950	·96	71	35	2485	72·7	84·2	60
	70	67	4690	37·5	52·5	3175	·94	62	47	2914	67·7	92	63
29	78	81	6320	65	65	4210	·91	69	58·5	4030	66·7	96	63·7
Field Currents: First Converter, 1·9 Amperes; Second, 1·95. (Second, Under-excited.)													
30	68	39	2650	37·5	33	2600	1·0	63·5	21·3	1350	98	52	50·9
31	65·5	52·5	3440	36·5	43	3200	1·0	58	34	1972	93	61·7	57·3
	69	66·5	4580	36·1	54·5	4160	1·0	61	47	2870	91	69	62·6
32	64	81	5174	33	67	4370	·96	52	59·5	3090	85	70·7	59·7

§ 4. To illustrate the difference between theoretical and actual losses Table VIII. was prepared. The heating was calculated by the formula $Pu = q\,r\,i^2$, q having the following values, and r being the resistance per radian of armature circumference :—

Table VII.
Values of q.

—	First Converter.		Second Converter.	
	Single-phase.	Three-phase.	Single-phase.	Three-phase.
$k =$	1·285	1·74	1·375	1·75
$\cos\phi = 1$	14·11	3·85	13·99	3·85
$= ·9$	19·82	4·37	18·55	4·62
$= ·8$	25·27	5·61	22	5·61
$= ·7$	33·52	—	30	—

Table VIII.
Watts Lost in Armature.

Single-phase				Three-phase.			
First Converter.		Second Converter.		First Converter.		Second Converter.	
Cal.	Obs.	Cal.	Obs.	Cal.	Obs.	Cal.	Obs.
915	860	225	690	318	906	107	294
955	914	435	796	475	996	202	374
1,121	1,510	650	760	727	1,278	333	432
1,585	1,450	876	998	1,165	1,498	625	462
2,120	1,910	1,150	1,294	1,685	1,700	952	490
745	904	348	649				
2,720	2,296	1,440	1,344	190	343	69	992
				297	740	140	632
531	790	205	565	272	1,100	226	565
995	1,000	475	695	620	1,515	432	261
1,520	1,536	725	914	1,015	2,100	696	180
4,100	2,902	1,260	1,468				
				212	50	78	1,250
655	820	200	725	380	240	200	1,228
982	1,044	387	816	614	420	378	1,290
2,175	1,760	800	1,290	913	840	607	1,280
2,715	1,992	890	1,508				
1,160	740	255	615				
891	700	304	635				
805	780	250	605				
1,000	1,060	432	725				
1,350	1,220	850	850				
2,120	1,660	1,440	1,130				

Values of r, ohms per radian.
First Converter, ·036 (S. and M.).
Second Converter, ·0446 (Holmes).

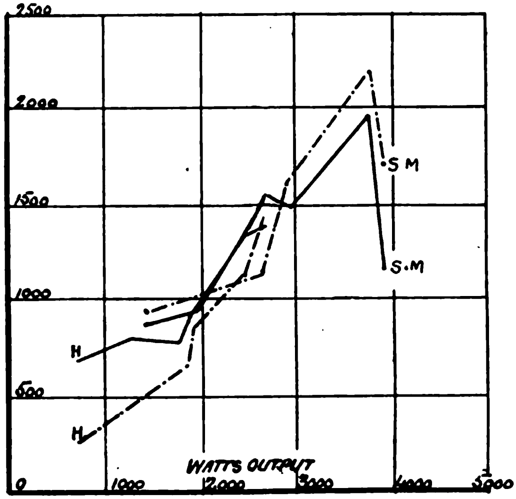


FIG. 11.—Second Under-excited.

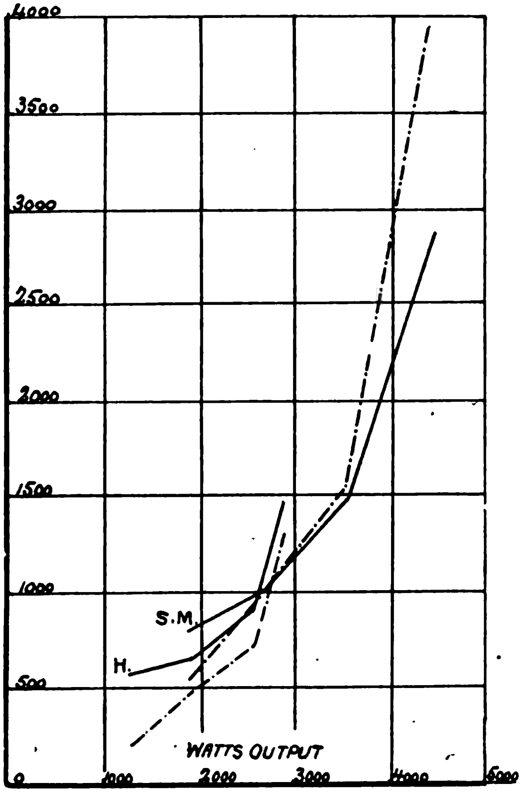


FIG. 12.—Second with Normal Excitation.

The general differences between observed and calculated losses may be better seen from Figs. 11 to 17, drawn Table VIII., the former being shown by full lines, the latter by dotted. In all the curves the ordinates are armature loss in watts, the abscissæ output of each machine. In the single-phase tests the first converter losses were in most cases in excess of those in the second, but the difference between observed and calculated loss was greater in the second than in the first. The three-phase curves are more remarkable. In Fig. 15, which refers to over-excitation of the second machine, the differences are much less in this than in the first. Fig. 16 at nearly normal excitation shows a reversal, which is more strongly marked in Fig. 17, where the second converter field is very weak. The inevitable conclusion from this last set is that the armature reaction harmonic is of sufficient strength to

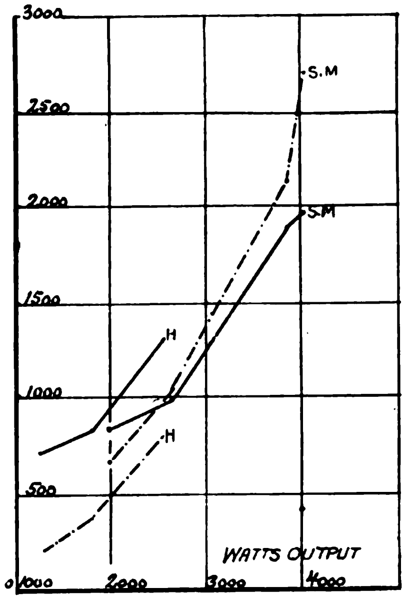


FIG. 13.—Second Over-excited.

disturb the whole circuit, so that the magnetism is rapidly weakened and strengthened in the solid magnet frame sufficiently to cause considerable loss of energy, and that a *change of excitation in the one machine can cause a disproportionate change in the losses of the other,* unless by skilful design and the use of damping coils these fluctuations in the magnetic circuit are minimised. In comparing these machines with motor-generators, it should be remembered that there are similar disturbances in synchronous motors. Beats can always be heard, and each of these means a loss of energy by eddy currents in the iron of the magnetic circuit. In Fig. 18, I have drawn from Tables V. and VI.

* *Vide* Kapp. *loc. cit.* p. 475.

the separate efficiencies of the machines for three-phase working, in which again there is a remarkable effect. The efficiency of the first converter when the second is under-excited *falls* instead of rising with the load, as much as 18 per cent. in one case, *its own field being maintained constant.* This again points to an abnormal increase in the

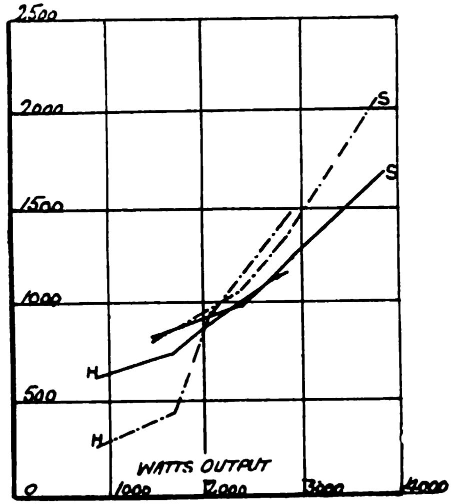


FIG 14.—First Over-excited.

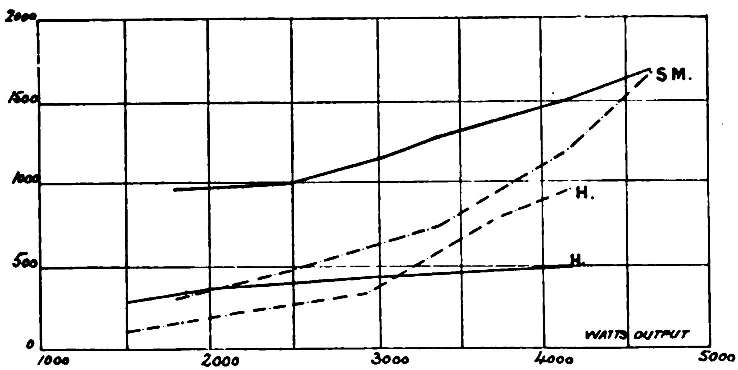


FIG. 15.—Over-excited.

eddy-current losses. There is also a curious drop in curve I_3, which indicates that the sudden loss of total efficiency shown in Fig. 10 for under excitation takes place in the first converter. It remains, then, to prove experimentally that these losses are caused by armature reaction, and to estimate their magnitude.

§ 5. I have worked out in a former paper * a numerical example of the losses due to eddy currents in magnet cores. These can be calculated when the dimensions and conductivity of the core and the ampere-turns producing the change are known. Thus if c be the radius of the core, l its length, μ the permeability, ρ the specific resistance, f the frequency of alternation of magnetism, and (I T) the

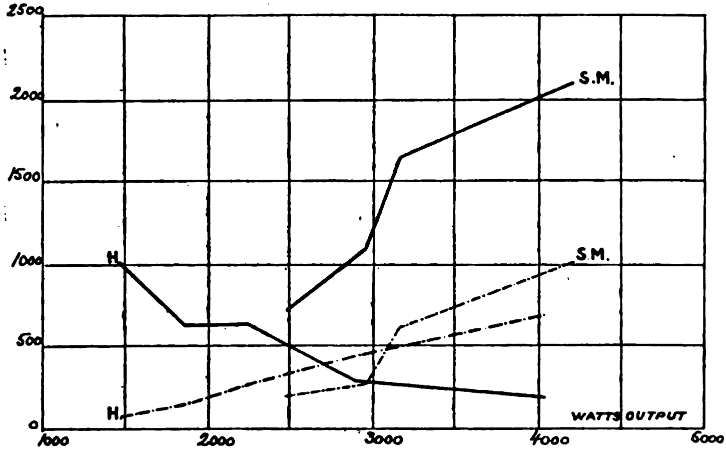


FIG. 16.—Slightly Under-excited.

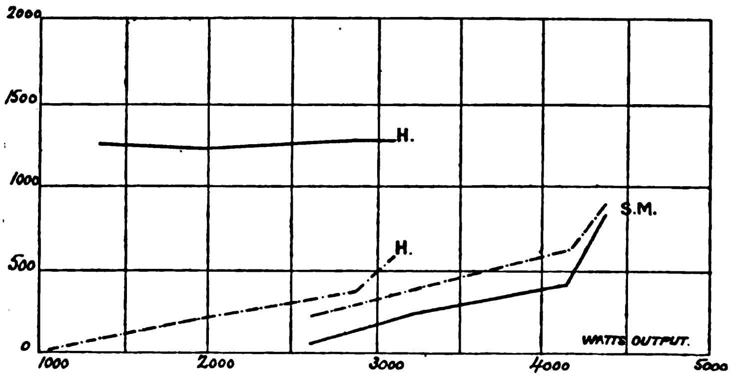


FIG. 17.—Under-excited.

maximum value of the ampere-turns causing the change—this being sinusoidal—then to a first approximation, the watts lost †

$$w = \frac{4 \pi l}{\rho} (\pi^2 c^2 \mu f) (\text{I T})^2 \, 10^{-7}.$$

* "Rotary Converters and Phase Swinging." *The Electrician*, Sept. 27 and Oct. 4, 1901.

† Heaviside, *Electrical Papers*, vol. i. p. 353.

To apply this to explain the difference between the observed and calculated losses it is first necessary to know the ampere-turns of armature reaction for any given condition of working. This was first done in these experiments by placing a hot-wire galvanometer across the otherwise unused series windings of the Holmes machine, these forming an exploring coil of 58 turns. About one volt was observed when running light, and photographs were taken showing the influence of phase swinging on the magnetic circuit when unprovided with damping coils. It occurred to me later that this voltage is sufficient

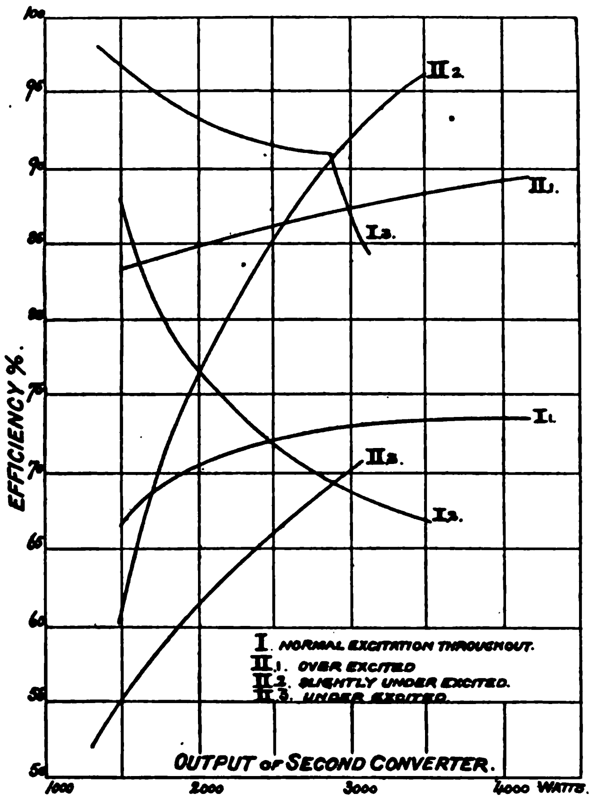


FIG. 18.—Variation of Efficiencies—Three-Phase.

to give good readings using the oscillograph as a dead-beat galvanometer, and I ran the oscillograph motor at the same time to see whether the harmonics of armature reaction could be directly observed. The results are shown in Plate I., the corresponding conditions being given in Table IX.* These curves are records of the

* The letters N, E ; U, E, etc., in the top row of numerals indicate the excitations of first and second converter respectively for each vertical column of curves.

rapid magnetic changes occurring within the core when this is worked at various saturations and with different values of armature reaction. They are, in effect, the voltage in the secondary coil of a transformer of which the magnetic frame is the core and the armature the primary. They are interesting, as showing, for the first time, I believe, what kind of action really goes on within the magnetic circuits of these machines, and, I have reason to think, of all kinds of dynamo-electric machinery, for I have obtained similar curves (Fig. 19) from continuous-current motors separately excited, driven from cells, and running light. The most curious point, I think, about the curves is the absolute constancy of form observed, except when a phase swing starts. All the ripples remain steady, and the curves can always be repeated. The same applies to the records of Plate I. This method of examination seems to me to afford a most delicate test of whether the armature is perfectly symmetrical in the gap, and should be

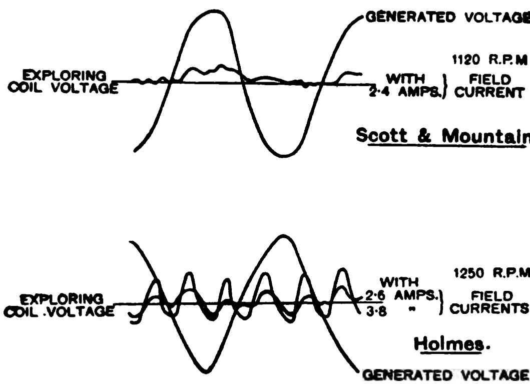


FIG. 19.—Oscillations of Magnetic Fluids, in Separately Excited Continuous-Current Motors Running Light.

useful in the study of flicker, or to indicate the magnitude of the disturbances, mechanical or magnetic, caused by the armature running out of truth. The records of Plate I. are no doubt complicated by the presence of these oscillations, especially the more rapid movements in the three-phase curves.

A detailed analysis of the curves in Plate I. would be very laborious, but some general conclusions may be drawn. Taking the first converter single-phase set first (curves 16 to 20 in Plate II.), it is seen that the light load losses are practically the same for all excitations, and that over-excitation more than doubles them for the same load, for the amplitudes of the curves are much the same, and the strip resistance was 16·1 ohms in 16, but only 6·1 in 20. The first three and 20 show a change of phase of the harmonic of about 45 deg., backward in 16, 18, and 20, forward in 17. Under-exciting the first machine causes the harmonic to lag with respect to the voltage more than in the other cases. This double frequency harmonic alternately weakens and

strengthens the flux in the gap, and this can be seen by 19, where it is in the first half opposite to and in the second in phase with the voltage. The motor reaction, curves 1 to 5, shows a remarkably constant type; there is a quadruple harmonic present, and the phase of this is moved 180 deg. of its own between 3 and 5. The reason for the existence of these still higher waves and the meaning of this shift of phase I have not had the time to examine more fully,* but it is of interest to see that the same changes occur in the three-phase curves, and that, as before, the losses are greatest with an over-excited first converter.

TABLE IX.

—	Curve.	1st conv. Field Current.	2nd conv. Field Current.	2nd conv. Con. cur. output.	Total ohms in strip circuit. Light.	Total ohms in strip circuit. Loaded.	Revs.
Single-phase (Holmes)	1	2	1·93	28	21·1	21·1	1,150
	2	2	2·72	32	21·1	21·1	1,000
	3	2	3·29	34·5	6·1	23·1	1,075
	4	1·6	2·7	22	13·1	23·1	1,000
	5	3·1	2·7	31·5	29·1	33·1	1,020
Three-phase (Holmes)	6	1·9	3·62	34	3·1	4·1	1,000
	7	1·9	2·4	41·7	4·1	4·1	1,020
	8	1·9	1·95	30	4·1	6·1	1,000
	9	1·6	2·7	20	2·1	2·1	1,000
	10	3·1	2·7	29	11·1	11·1	1,000
Three-phase (Scott and Mountain)	11	1·9	3·62	33	2·1	2·1	900
	12	1·9	2·4	39·5	2·1	8·1	1,030
	13	1·9	1·95	30	2·1	4·1	1,000
	14	1·6	2·7	20	2·1	2·1	1,050
	15	3·1	2·7	20	2·1	2·1	1,000
Single-phase (Scott and Mountain)	16	2	1·9	24	4·1	16·1	1,060
	17	2	2·7	20	4·1	14·1	1,080
	18	2	3·2	30	4·1	9·1	1,060
	19	1·6	2·7	non-p.	6·1	6·1	1,060
	20	3	2·7	15/25	6·1	6·1	840

To return to the determination of the ampere-turns of reaction. Let e be the voltage generated in the exploring coil, as found by a hot-wire galvanometer or from the curves, and let there be s turns on the coil. Then, when f is the frequency of oscillation (which will not be simply that of the machines if there are harmonics),

$$e = 4\ N f s / 10^8,$$

* It varies with both excitation and load.

where N is the mean flux through the coil. Here e is root mean square, and N an ordinary average, hence the true value of

$$N = \frac{e}{4fs} \cdot \frac{\cdot 637}{\cdot 707} \cdot 10^8.$$

but s is 58 on the Holmes machine, 55 on the Scott and Mountain, and f and e are observed; thus N is known. Now, N = Magnetomotive force/reluctance. Thus writing

$$N = \frac{4\pi}{10}\frac{it}{R}, \text{ the ampere-turns } it = \frac{NR}{1 \cdot 257}.$$

The maximum value for sine waves is 1·57 times this. Therefore

$$(IT) = 1 \cdot 25\, NR.$$

For the Holmes machine, R = ·005, as found from the magnetisation curve for 2·7 amperes, so that

$$(IT) = 2{,}420\, e/f;$$

and when the speed is 1,000 revolutions per minute,

$$(IT) = 146 \text{ per volt in the exploring coil.}$$

For this machine the mean length of solid iron core is 100cm., the radius 7·8cm. Taking the specific resistance as 10,000, and the permeability as 100, the watts lost at 1,000 revolutions per minute are *125* per *100* maximum ampere-turns.* Thus we have finally, since the loss depends on the square of the reaction ampere-turns, *266 watts per volt*. Considering the double frequency harmonic, this loss is reduced from 266 to 65 watts. When there is little or no phase swinging, the voltage is from two to three at medium loads. The oscillograph calibration was 2·1 cm. deflection per volt with 10·1 ohms in circuit, from which the amplitudes of Plate I. may be worked out in volts.† Taking an equivalent sine maximum of 2·5 volts, with the double frequency harmonic of Curve 2, there are *102 watts* lost by eddy currents in the magnet core. It will be seen from Fig. 12 that this accounts for a good deal of the discrepancy between the observed and calculated loss in the Holmes machine, and I think that all the wide differences are due to the same cause.

§ 6. *Effect of Armature Reaction on Wave-Form.*—The relation between excitation and phase displacement has been shown in Figs. 4, 5, and 6. These were verified by direct observation in the oscillograph and the waves sketched. The voltage curve remains singularly constant in shape under all conditions, but the current wave, depending as it does on the phase relations of the two machines, is very sensitive to changes in the magnetic circuits. The chief cause of the variation of form is the harmonic of armature reaction, and the phase of this changes considerably with regard to the main wave.

* Magnetic leakage reduces the intensity of the eddy currents towards the yoke, thus diminishing the loss, but the working permeability is about 400, and the eddy current loss is directly proportional to this.

† The curves as printed are about quarter full size.

Plate II. contains a selection from the wave-forms sketched. The current curves of Plate II. are not all to the same scale. Tables V., VI., and IX. give the true values. Curves 1 to 22A are for a single-phase working, the rest for three-phase. On all the curves but 22 and 22A the conditions of excitation are indicated by the letters O E, U E, or N E, signifying over, under, or normal excitation. In 14A the phase displacement from lag to lead as the excitation is increased in the second converter is shown; 22 gives the magnitude and nature of the wave changes during moderate phase swinging, and 22A is the single curve in which the brushes have been moved from mid-position, A_1, corresponding to a slight backward shift, and A_2 to the extreme backward shift when the sparking was too heavy to be long continued. The first set, from 1 to 6, were taken after the readings of Table IV. These were approximately repeated, as in Table X., to which the curves correspond. In these the full effect of change of excitation can be seen both on form and phase. The strong harmonic of Curve 1 always appears when the second machine is fully excited and the field of the first gradually reduced, the speed being maintained constant by varying the armature current. The lateral shift of the harmonic is most marked from 1 to 2, the other curves showing chiefly a variation in its amplitude.

Table X.

Field Current of First Converter, 2 Amperes; Second, 3·7 Amperes.

No. of Curve.	First Converter input.		Second Converter input.				Second Converter output.	
	V.	A.	V.	A.	W.	Cos ϕ.	V.	A.
1	92	13·5	62	13·6	532	·65	0	0
2	82	37	54·5	40	2,190	1·0	79	19·5
Field Current of First Converter, 2 Amperes; Second, ·7 Amperes.								
3	80	35·7	48	39·5	1,910	1	68	19·4
4	82	13·5	52·4	20·5	472	·44	0	0
Field Current of First Converter, 2 Amperes; Second, 2 Amperes.								
5	79	16	48	30	504	·35	0	0
6	78	30	45·6	37·5	1,484	·87	61	15

Curves 7 to 21 were taken simultaneously with the readings of Table V., as indicated, and it is of interest to trace the nature of the change with load in each case of excitation. In 11, for example, the current being more than double that of 7, the harmonic has moved over 60° and its amplitude increased.

The curves from 23 to 40 are for three-phase working, and partly correspond to Table VI. In the last eight the first machine was driven mechanically by belting, but the differences between these and the previous nine are not important. It is evident that the field distortion is extremely small when working three-phase compared with single-phase. With the exception of a weak third, harmonics are almost absent. There is a slight distortion of the field as in a continuous-current motor, which is met in practice by suitable brush displacement, but phase-swing is difficult to start, and is not maintained to the same extent as in single-phase running.

It may be concluded from these experiments that over-excitation of the second machine or motor improves the stability of the system, but that if the generator or first machine is under-excited, although the ratio of the flux densities in the gaps may be kept constant, there will be both an increase in the eddy-current losses and in the instability of working by reason of phase swinging. It is more economical then to expend energy in over-excitation than to allow phase swing to start and stop it by damping coils. These are necessary in any case where there is a periodic irregularity in the generator speed, but they depend upon a well-marked change in the magnetic circuit, and when this is saturated the magnitude of the disturbance is less.

Eddy currents in continuous-current machinery have been previously thought of as almost entirely located in the armature and pole-faces. From these tests it is seen that with a periodic oscillation through the whole magnetic circuit the losses in the solid cores are considerable, and I believe that the greater part of the eddy-current loss found by any of the usual tests takes place in the solid frame. If this is to be prevented, the mechanical construction must be as accurate as in engine fitting. The pole-faces must be bored smooth and set to gauge. The armature must be as true as a gun barrel and perfectly centred. Its shaft must be stiff enough to prevent the least bending and must not whirl at any speed, for the most violent magnetic changes will be set up if this occurs. If it is attached to overhung pulleys or flywheels, which cause bending, these must be compensated as in a balanced engine. Of course, all this is if it is worth doing. It is merely a question of first cost—the user pays for the energy lost in the damping system.

I hope that these experiments will be preliminary to others on sub-station machines under working conditions, and a rather lengthy series of tests on the effect of brush position on efficiency and wave-form has already been made. I think it will be admitted that our experimental knowledge of the reactions in alternators and converters, and in continuous-current machinery also when subject to changes in the mechanical torque, is at present imperfect. I venture to hope that the experimental methods of studying the changes in the magnetic circuits given in this and last session's paper* will contribute a little to a more thorough knowledge of what really goes on within both fields and armatures of dynamo-electric machines in general, and lead to an improvement in their efficiency and stability of working.

* The *Electrician*, May 30 and June 13, 1902; the *Electrical Engineer*, April and May, 1902.

Mr. JOHN H. HOLMES (*Chairman*) said that the Institution was highly favoured to have had such an important paper read before it. Dr. Thornton's previous paper had been of very great interest and this was a continuation of it, while the points he had now brought out were very interesting. It had probably been recognised, to some extent, that changes took place in the field magnets of continuous-current dynamos when there was something wrong with the armature, if it was very much out of balance, or if there was a short circuit, but we had no idea as to what those changes actually were. The methods introduced for detecting changes in these magnets were very ingenious, and seemed to make the thing much clearer. The question of rise in voltage on field coils of dynamos had certainly been observed and had led to inquiry. It was quite possible that the extraordinary rise in voltage noticed on shunt windings when the armature was very much out of balance, or what the Americans call the "bucking" of dynamos, might find some explanation in this paper. Mr. Holmes.

Mr. G. RALPH, after congratulating Dr. Thornton on his excellent paper, said that, unfortunately, his knowledge of the subject was so slight that he could not criticise any portion of the paper, but he had no doubt that many others, like himself, had occasionally in the course of their work, met with some phenomenon which was puzzling at the time, and for which they could not find any explanation. Cases like these should be taken to friends like Dr. Thornton to be solved. Mr. Ralph.

It might be interesting to them to describe a curious effect which came under his notice a few years ago. He was engaged in carrying out some efficiency trials of direct-coupled engines and single-phase alternators at a Corporation Supply Station in the South of England. The conditions were as follows:—The engine was a double-cylinder single-acting engine. The revolving armature was of the disc type, with no iron in it, of the well-known type made by Siemens, Ferranti, and others. The alternator field was separately excited. When the machine was running with *no* current in the armature, the potential across the exciting terminals of the field was 80 volts, and the exciting current agreed with this potential difference and the resistance of the field. When, however, load was put on and full current was flowing through the alternator armature, the potential across the exciting terminals rose 50 per cent. or more, although everything remained exactly the same as before, that is, the speed of the alternator and exciter was unchanged, the exciting current and resistance in the circuit remained unchanged and yet the mere fact of putting load on the alternator caused the exciting voltage apparently to increase to this degree. When this was first noticed it was concluded that the voltmeter had gone wrong. It was an electro-magnetic type of instrument. This was taken off, and a Cardew hot-wire voltmeter and also a Kelvin multicellular electrostatic voltmeter substituted with exactly the same result. A similar effect was noticed the following day on the trial of a smaller alternator. When he returned to the works after these trials were over he tried to get the same effect on other alternators in the place—at the time in the course of construction—and failed utterly. Some doubt was then cast on his figures, and the engineer in charge of the station

Mr. Ralph. where the effect had been noticed was written to and asked to try again and his (Mr. Ralph's) figures were repeated every time. He would like to ask Dr. Thornton if he thought an effect like this would be produced by armature reaction causing a very strong fluctuation in the field magnet cores. He believed that in these particular alternators the field was fairly weak, which, as pointed out in the paper just read, would magnify any evil of this sort. He had never heard a satisfactory explanation, and thought it might be interesting to mention the case.

Mr. Heaviside. Mr. A. W. HEAVISIDE then proposed a vote of thanks to Dr. Thornton, and in suggesting a visit to the dynamo room of the college, said it would be very profitable to see the actual experiments.

Mr. Eugene-Brown. Mr. E. EUGENE-BROWN seconded, adding that he was well acquainted with the subject itself, and was sure the experiments with the oscillograph would be full of interest.

[The members then proceeded to the dynamo room, where Dr. Thornton went through and explained the experiments, and also answered the questions which were put to him.

The discussion was continued informally in the engine room while the experiments were being shown. The curves of Plate I. were projected from the oscillograph on to a screen, and the change from one to the other condition made gradually by the field rheostats. Periodic movements in the curves, due to phase swinging, were started by throwing load on and off the second converter. Messrs. Holmes, Heaviside, Snell, and Ralph took part in the discussion, and in reply to them the following points were brought out by Dr. Thornton :—]

Dr. Thornton. Dr. W. M. THORNTON : It is not possible to prevent armature reaction itself, and it is therefore necessary to check, in every possible way, the communication of disturbance to the magnetism. This may be done in any machine by damping coils surrounding the poles, by preference, close to the armature. These act most efficiently when the iron frame is solid, and depend chiefly on the eddy currents started by magnetic waves sent radially into the core by the strong currents induced in them by slight changes of magnetism. Since they are useful even when the iron is laminated in making any oscillation more dead beat by opposing the initial change I would advocate laminating the magnet frame of continuous current machines; for, in the first place, it would diminish eddy current loss. It is generally taken that the no-load eddy current loss, which can be found, remains substantially the same at all loads, but according to these curves this loss is about twice as great at full load in the second converter. In cases of parallel running, with compound traction machines for example, the currents in the equaliser circuits, and therefore the voltages would more quickly adjust themselves. Design in general is simplified by the accuracy with which the permeability of these plates can be found.

The value of amortisseurs in preventing fluctuations is such that one may reasonably forecast the time when every large machine, either continuous or alternating, will be fitted with them, for though by the use of high-speed engines and turbo-generators, irregular turning movement is less, yet the governing of both is far from perfect, and with the small moment of inertia of the latter, sudden or periodic load

Dr. Thornton.

may be very disturbing to the magnetic circuit unless protected in this way.

These fluctuations do not entirely depend on armature reaction, for as shown by Fig. 20 they are obtained in the exploring coils when *no current is passing in the armature.* That is to say, they exist by reason of the variation of the reluctance of the air-gaps due to the armatures running slightly out of truth. It is not possible in either case to observe any side movement, nevertheless, both armatures must be slightly eccentric in the gap or the shafts bent. A quadruple harmonic would be caused by a bent shaft or by the armature "whirling." The fact that the effect is greatest when the field is strongest confirms this view.

In Fig. 20 the current required to drive the oscillograph (about ¼ ampere) was being taken from the slip-rings. To eliminate the effect of this the first machine was used to give current for the oscillograph motor only, at the same time connecting one strip to the exploring coil on the second machine, which was belt driven, and entirely disconnected from the first. The curves remained the same shape but were slightly smaller. It was not possible to draw or photograph them by reason of their slow procession across the screen.

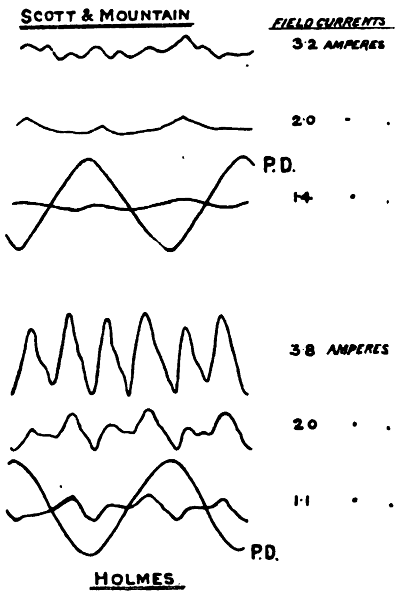


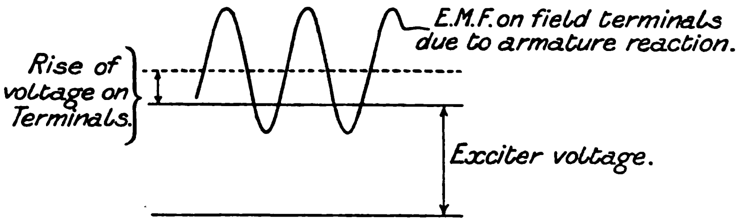
FIG. 20.

With regard to Table VIII. the armature losses are calculated from the continuous current having regard to the irregular distribution of current in the conductors. The energy taken into or supplied by the armature is a function of both voltage and current, the energy flux entering the conductors from the surrounding medium at right angles. One may thus follow the transfer of energy from the source of supply to the eddies in the iron through the magnetic flux acting as an elastic intermediary, and see it dissipated there without the armature current showing all that is going on, though there will be inevitably either a rise in current or drop in voltage whenever the effect is taking place. To obtain a general expression for the losses covering both voltage and current changes, is, I think, impracticable, but by reference to Table VI., curves 30 to 32, it will be seen that whenever there is a great difference between the observed and calculated losses it is accompanied by a large drop in voltage.

In reply to Mr. Ralph's question the effect is, I think, as follows :—

Dr. Thornton.

There was first an alternating armature reaction superposed on the constant excitation. This field was weak, and when the armature was strengthening the field the permeability of the core would certainly be less than when acting against the field magnets. The alternating voltage induced in the field windings depends on how this permeability varies. If it is simply harmonic no rise in voltage can, I think, occur across the exciter terminals, but if it varies (as, for example, in the large wave of



curve 1 Plate I. in the paper) with a pointed top to the wave, that is the point where the voltage will be greatest, for there the permeability is changing most rapidly. In this case the induced voltage in the field windings will be greater above the line of exciter voltage than below and there will be a rise of voltage at the terminals, though the exciter voltage remains constant. The instrument must have been capable of reading both alternating and continuous voltage.

I wish to thank several senior students who have helped me in this work.

NEWCASTLE LOCAL SECTION.

RAILWAY BLOCK SIGNALLING.

By J. PIGG, Associate Member.

(*Paper read at Meeting of Section, December* 15, 1902.)

The subject of signalling generally is of the most interesting character possible, and code signalling of some form or other seems to have been in use for the conveyance of intelligence to points beyond the scope of man's vocal organs during all periods covered by history. If time permitted we might commence with a quotation from Exodus, and pass on by easy stages to the methods of signalling of ancient Egypt, the heliograph of Alexander the Great,* the torchlight signalling of the Romans, the adaptation of the Greek clepsydra to alphabetical signalling, the drum, smoke, and fire signals of savage peoples, the later beacons and watch-towers of our own and other countries, the revival of torchlight signalling between the Scottish mainland and the Shetland Isles by the Rev. James Bremner early in the eighteenth century, and so to the achievements of the brothers Chappé on the Continent with semaphore signalling, and Lord Murray's shutter form of telegraph in this country in the period immediately preceding the introduction of the electric telegraph. It is interesting to remember that although accounts of the introduction of the electric telegraph now read like ancient history, yet we are still comparatively near to the era of the semaphore telegraph. Although formally adopted by the French Directory in 1793, Chappé's system was not fully completed in Russia until 1858, so that there may be some here who, without being of a patriarchal age, and probably taking but little interest in the subject at the time, may still be said to be contemporaries of the semaphore telelegraph.†

The more particular form of signalling to which this paper refers has also an historical side, which is of considerable interest to the student of the evolution of railway signalling. There are, moreover, other aspects of the subject which are of great importance. These are the statistical, involving consideration of reams of figures relating to the development of the system and its effects; the constructional, with its sight-destroying and brain-puzzling diagrams, illustrating the principles of design and the circumstances to be met; and the operative, with its enormous mass of detail for working purposes. All these points of view, including the historical, are of the greatest importance

* See Presidential Address of Sir Henry Mance to Institution of Electrical Engineers, January 14, 1897.

† For further information on pre-electric telegraphs see a most interesting lecture by Mr. Alderman W. H. Bailey (now Sir W. H. Bailey) at Salford in 1883, "Telegraphs of the Ancients."

in their several ways, but they require more time to even skim them lightly than is available here.

There is, however, still another aspect of the subject which, to the writer, seems to be of supreme importance—the effectiveness of the system—or, in other words, its adequacy for the purpose for which it has been designed. However interesting other aspects may be, there are none of such importance as this. Freedom from failure—and the consequences—is the touchstone of any system. When, as in railway signalling, the consequences may be serious, the necessity for reliability is greatly increased. We might illustrate this aspect of the subject by quoting figures to show that travelling by railway is vastly safer than by the old stage coach, the newer motor-car, or even, in view of recent lamentable occurrences, the electric tram, inasmuch that a smaller proportion of travellers are killed or injured by the former than by any of the latter methods. It is the present proud boast of English railways that they have not killed a single passenger through an accident to the train in twelve months, and such a record, considering the millions carried, is a magnificent testimony to the care and attention devoted by those responsible for the organisation, direction, and operation of the enormous traffic carried on our railways. Yet accidents do unfortunately occur, and, if I may so put it, it is small comfort to the sufferer to know that he is only a unit in a small percentage of fatalities, and should be glad that the percentage is not larger.

OBJECTS OF BLOCK SYSTEM.

There is no need on this occasion to labour the point of what is meant by the term "block." Quoting from the explanation given with the standard rules, we find that "the object of the system of block telegraph signalling is to prevent more than one train being in the section between two block signal-cabins on the same line at the same time," or from the Board of Trade "Requirements in regard to the Opening of Railways": "The requisite apparatus for providing by means of a block telegraph system an adequate interval of space between following trains, and, in the case of junctions, between converging or crossing trains." These extracts, by the use of the word "telegraph," seem to limit the term "block" to the electrical signalling apparatus, and ignore the outdoor mechanical signals as part of the "block system." Definitions of the system which may be deduced from these quotations seem to the writer to be narrow, and inadequately indicate the functions of the two main classes of apparatus used for the regulation and control of traffic. Certainly it is impossible to consider either class alone in connection with the results to be obtained. However, one oftens obtains a more vivid idea of a comparatively unfamiliar subject by the use of a simile, and the following quotation from a popularly-written article in the *Pall Mall Gazette* has at least the merit of being graphic, if incorrect: "The world-famous block system, which, to furnish a simple parallel, decrees that no train may leave the bottom of a flight of stairs until both the latter and the landing beyond have been guaranteed clear."

The fundamental basis of block signalling is, therefore, the preservation of "an adequate interval of space" between trains, whether "following," "converging," or "crossing"; the object is safety; and by convention or rule or regulation it is provided that not more than one train shall occupy one pair of rails of a certain portion of the line at one and the same time. For signalling purposes the line is divided into discontinuous sections, or blocks, and cabins are erected at suitable points in which, as required by the Board of Trade, the means of actuation of all points and signals connected with the running lines are assembled, and in which is also placed the electrical signalling apparatus. The *block section* for the time being is the distance between the two cabins in electrical communication with each other at the time. These two cabins may not be the two nearest to each other; under certain circumstances intermediate cabins may be switched out and become inoperative for a time. Ordinarily the space limit between trains is the length of the *block section*, and it is never less than this; but where the distance is 400 yards or less the *space limit* may be two or three such sections. It is not necessary that the space limit be the same at all parts of the line, and, as a matter of fact, no attempt is made to obtain uniform distance between trains. At some places it may be only a few hundred yards, and at others, again, it may be several miles. Nor is it necessary that the space limits within any given portion of line should be constant. In many cases, as already alluded to, means are provided by which, for economical reasons, the sections and space limits may be purposely varied. In every case, however, the minimum distance to be observed depends upon traffic considerations, with which we are not concerned here, and upon the distance in which the heaviest and fastest trains can be brought to a stand on the gradients obtaining. In some cases where there are heavy gradients we may find that whilst the *block sections* are the same for the up and down lines, the *space interval* is greater for the line with the falling than for that with the rising gradient.

Main Divisions of Apparatus.

A cursory examination of the subject shows that the apparatus employed in railway signalling may conveniently be divided into two great classes—the outdoor mechanical signals, and the electrical signalling apparatus. The former are used for the actual control and regulation of the movement of traffic; the latter is provided for perfecting the arrangements for the exhibition of the proper signals for the time being, and is, therefore, an auxiliary. The whole art of railway signalling, therefore, consists in the exhibition of suitable signals to the controllers of trains as they approach the sections or blocks.

The forms of the mechanical signals in use in this country are well known, but there are one or two details respecting them which may be touched upon here. A certain class of signal, the "distant," may be passed when in the "on" position. Its indication is of a cautionary character only when in the position named, and shows that the section ahead has not been prepared for the free passage of the train, and that

the driver must be prepared to stop at the next signal in order, the "home." Drivers, however, are by rule required to be prepared to stop at any obstruction that may be found to exist between the "distant" and the "home." Naturally, the positions of "distant" signals must be at such distances from the "home" signals as to allow any train to be brought to a stand at the latter if necessary, and the location of the "distant" is also always made with a view to a clear sight of it being obtained as early as possible before it is actually reached. Other signals than the "distant" are "stop" signals, which must not be passed by trains when in the "on" position, unless special permission is given. Such permission may be given by "calling-on" signals which have a cautionary character when in the "off" position; or by lamp, flag, or hand signals, supplemented in some cases by verbal and in other cases by written instructions. 'Home," "starting," and "advance" signals are all "stop" signals, as are also siding and cross-over road signals.

"Stop" signals have other characteristics than those already referred to. Thus besides being indicators of the conditions existing with reference to the continuance of the journey, they are also position signals in that they mark the points which must not be passed by any portion of a train when the signals are in the "on" position without special permission. They, therefore, are used to protect the fouling points. At junctions the "home" signals—and the "distants" where more than one are provided—are also route indicators for the divergent lines, since each such line is provided with a separate "home" signal. These signals are erected under the same rule for all places, and the recognition of the road prepared, by drivers, is thereby facilitated.

Interlocking of Points and Signals.

The means of actuation of all signals have to be interlocked with each other, and with the means of actuation of the points, so that the latter must be set before the signals for them are lowered; so that conflicting signals cannot be lowered at the same time; so that points cannot be moved when the signals are in the "off" position; and the points must, as far as possible, be interlocked amongst themselves so that risk of collision is avoided. Cabins must be so situated as to provide the best possible view of the line, and to enable the signalman to see the arms and lights of the signals and the working of the points. Where signal arms and lights cannot be seen they are to be repeated in the cabin. Facing points must be avoided as far as possible, and must not be more than 200 yards from the cabin, and trailing points not more than 300 yards. All facing points are to be fitted with facing-point locks and locking bars, and with means for detecting failure in the connection between the signal cabin and the points. The length of the locking bars must exceed the greatest wheel base between any two pairs of wheels of vehicles in use on the line, and stock rails are to be tied to gauge by iron or steel ties. All points, whether facing or trailing, are to be fitted with double connecting rods, and must be worked or bolted by rods and not by wires.

These conditions all make for safety, and on their stringency it is unnecessary to comment here. It is impossible to over-estimate the importance of the interlocking of points and signals at important junctions or busy centres of distribution. Such places as busy passenger station yards, whilst they can be, and are, worked without the ordinary electrical portion of the block system, could not possibly be worked without interlocking at anything like their present efficiency, or with the freedom from accident that obtains at present. The interlocking in busy yards not only exists between the different levers in any one cabin, but there is, necessarily, also a large amount of inter-cabin control where a yard is worked by a number of cabins. How intricate is the control which must be established will be readily seen from an inspection of the signalling plan of any large station yard.

Power Signalling.

We have, hitherto, considered the working of points and signals exclusively from the point of view of manual operation. The tendency to the use of power, under manual control, for this purpose is at the present moment becoming very marked. The working of points and signals by electrical power has, of course, been in operation at Earl's Court Station on the Timmis system for some time. The Great Eastern Railway Company has put down an installation of the Westinghouse electro-pneumatic signalling system at Bishopsgate, and the North-Eastern Railway has recently fitted up two cabins at Tyne Dock with the same system. The London and North-Western Railway Company has put down a large installation at Crewe, where all the necessary operations are carried out by electrical power. This system, commonly known as the "Crewe" system, is to be put down at an important junction on the North-Eastern Railway at York. Messrs. Siemens and Halske also have a very complete system of electrical power signalling, installations of which have been put down at various places on the Continent. It is impossible within the limits of a paper like this to enter into details of any system, or even to consider their advantages. The tendency to the use of power for the purposes alluded to, in preference to hand labour, is merely noted as a development which is just in its first stage. Nethertheless, it may be considered as certain that the subject has received careful attention from railway engineers, and that such installations would not be put down, even as experiments, unless there was a fair prospect of their being successful in promoting either efficiency or economy.

Electrical Equipment and Operation.

Turning, now, to the electrical equipment for the signalling of a railway, we find a large number of matters of great importance which the time available will not allow of discussing. Such points are the signalling of single lines, and the particular conditions to be complied with; the use of permissive systems of signalling, with recording instruments for certain classes of line; the employment of the telegraph and the telephone as auxiliaries in train signalling; gate-

crossing equipments; the repeating of signals, lights, points, etc.; the apparatus used to indicate when trains or vehicles are standing at a signal which is out of sight of the signalman, or where the line is not clearly visible; rail treadles or insulated rails and their uses, or other special devices which go to make a complete system. We have not even time for an analysis of the codes and regulations under which signalling is carried on; for a discussion of the relative merits of three-wire or one-wire systems; or for the much-debated question of the best form of instrument, from either the electrical point of view or from the operator's standpoint. The latter question is quite as easy of settlement as the question of the best arc lamp or the best motor, municipal *versus* private trading, provision for the depreciation of plant, or any of the numberless matters on which many people agree to differ more or less amicably.

The electrical equipment for a block section is very simple, but the amount of apparatus to be provided at any block station depends upon the character and importance of the place. If we take the simplest example of such a station, say a mere passing place, we shall find that where single-needle apparatus is employed the equipment will consist of two bells and four such instruments. One bell and two instruments will be in electrical communication with the block station on the up side of the cabin considered, and the remainder in connection with the cabin on the down side. The bells are for the purpose of giving and receiving information, or for the making of arrangements in accordance with the voluminous code which provides for all circumstances that may arise in connection with the working of traffic. The instruments are also used to a slight extent in connection with the code, but they have other and more important duties to perform, in that they are intended to indicate continuously the condition of the lines of rail they represent.* There are numerous forms of block instrument in use, each embodying, no doubt, its designer's idea of the best method of performing the desired operations, but with constructional details we are not at present concerned, and so far as their indications are concerned they are all alike in that they represent the condition of the line by convention only.

A study of the code and regulations for the working of traffic shows that there are three conditions of the line which the block instrument should indicate. These are:

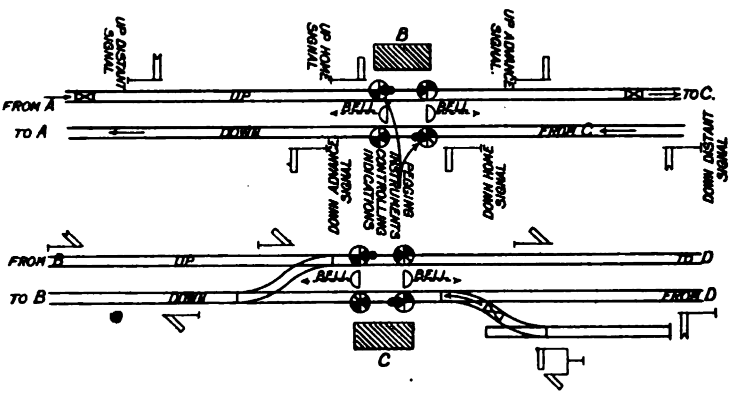
"LINE BLOCKED," "LINE CLEAR," and "TRAIN ON LINE."

The first is the indication to be given when the section is clear of trains altogether; the second is the indication required when the section has been prepared for a train, but which has not yet entered the section; the third is the indication provided to show that a train is actually passing between the two block stations. Each of these indications is "permanent," in the sense that it is required to be exhibited during the whole time the condition it represents continues; the indications on the two instruments representing a line of rails, in the two cabins,

* On the N.E.R. the use of the indicators in connection with the code has been discontinued since the paper was read.

are the same, and the indications are under the control of and made by the man towards whom the train signalled is proceeding—*i.e.*, at the exit of the section.

The operations necessary to the passage of a train may be briefly described, it being premised that the character of the train is immaterial for the present purpose. Suppose a train is approaching station " C " on the up line and will pass on to " D." Station " C " askes station " D " by code " Is line clear ? " (there are 11 variants of this signal). If the train may proceed, " D " replies by code to that effect, and gives an indication on the block instrument for the up line at his own station and at " C," which reads " Line clear." This indication remains until a further stage of the operations, and serves as a continual reminder to " D " that he has given permission for a train to leave " C," and to the signalman at the latter station it serves as a continuous reminder that he has obtained permission to forward a train. Under the conditions now obtaining the signalman at " C " may place his mechanical signals in the " off " positions to allow the train to proceed to " D."



When the train is leaving " C " the signalman there sends the " Train entering section " bell signal to " D," who must acknowledge it and change the position of the block indicators in his own and " C's " cabin for that line to " Train on line," and this indication serves as a continuous reminder to both signalmen that there is a train *in the section.* When the train has passed " D " and gone forward under precisely similar conditions, the signalman there advises " C " that the section is again clear by giving the " Train out of section " dial signal, and leaves the needle of the block instrument in the " Line blocked " position. In the diagram the various conditions may easily be followed.

Relative Responsibility of Signalmen.

If we consider the functions of the two signalmen, we find that for traffic in one direction one of them is more responsible than the other. The signalman at the exit is the person who gives permission for a train to enter the section, and before doing so he must assure himself that

the conditions obtaining are suitable. Further, he must arrange for its disposal on arrival at his cabin, and see that it is in such condition as will justify him in clearing the section after it has passed out. The signalman at the entrance to the section cannot, under normal circumstances, authorise a train to proceed without having obtained the permission given by the acknowledgment of the "Is line clear?" signal, and the giving of the "Line clear" indication. Hence the responsibility for the authorised progress of the train rests with the signalman towards whom the train is proceeding. The signalman at the entrance becomes the guardian of the section, and must protect against the entrance of a train by the exhibition of the proper signals. For ordinary double-line working one signalman is, of course, the sender for, say, the up line and the receiver for the down line, so that responsibility is averaged for the total traffic.

If we carefully consider the relationship existing between the two divisions of apparatus, we find, as already stated, that the electrical is an auxiliary to the mechanically-operated outdoor signals, and exists for the purpose of perfecting arrangements for the safe dispatch of traffic between persons charged with its control, situated at considerable distances apart, for the purpose of indicating the condition of the line between those persons at all times, according to fixed conventions or rules, and for the notification of its passage from point to point. The safety of the system consists in the actions of all parties to the movement of traffic being synchronised, and as this most important point is only possible by the aid of the electrical equipment, its value as an adjunct is extremely great.

If we look over the requirements of the Board of Trade with reference to the electrical portion of the signalling apparatus, we are at once struck with their meagre character as compared with the requirements for interlocking. The first requirement reads: "The requisite apparatus for providing, by means of the block telegraph system, an adequate interval of space between following trains, and in the case of junctions between converging or crossing trains." Then, curiously enough, under the head of "Interlocking," we have: "The signal cabin to be commodious, and to be supplied with a clock and with a separate block instrument for signalling trains on each line of rails."

If we contrast the wording of the requirements with reference to the operation of the two classes of apparatus, we cannot fail to observe the great difference in the degree of precision in the language employed. Referring to the requirements with regard to interlocking, we find that the signalman "shall be unable" to lower a signal until after the points are set for the road controlled by that signal; that "it shall not be possible" for him to exhibit signals which will give rise to a collision; and that "he shall not be able" to move points connected with a line the signals for which have been previously lowered. There is no similar precision in the requirements for the electrical apparatus, the references being as already quoted: "The requisite apparatus . . ."; "a separate block instrument for signalling trains on each line of rails." Turning to the standard code, we find the general regulation to read: "All fixed signals must be kept at danger except when it is necessary

to lower them for a train to pass; and before any signal is lowered, care must be taken to ascertain that the line is clear, and that the block telegraph and other regulations have been duly complied with."

Limitations of Ordinary Systems.

If we consider the limitations of such a system of signalling as has been outlined, we find that its greatest weakness arises from the want of interdependence between the two divisions of apparatus. Theoretically, the arrangements are perfect; one signalman acts as a check upon the other in so far as they are both concerned in any operation, and the interlocking checks inadvertent error in the operation of the outdoor signals at either block station in so far as fouling routes are concerned. But neither signalman has a complete check on the actions of the other, and as the operation of the mechanical signals is in no way dependent upon the block instruments, the operations need not necessarily synchronise, and interlocking will not prevent following collision where operations of the signals may be repeated without check. The sending signalman depends upon the observation of the man at the exit of the section when the latter accepts the "Is line clear?" signal, and must necessarily do so; the receiving signalman relies upon the man at the entrance to the section not to send trains into the section without the usual acceptance and subsequent notice of the change of position of the train, but is powerless to control his actions; and both signalmen rely upon the due observance by the drivers of trains of the signals exhibited for their guidance. Hence there are three independent persons engaged in the movement and control of traffic, any one of whom by a dereliction from duty may be the cause of accident. Accidents caused by deviations from the regula tions provided for their guidance have occurred frequently in each of the three conditions referred to, and a study of the Board of Trade inspectors' reports show that by far the greater majority of accidents to trains occur through the failure of one or other of the persons named to carry out his duties in the manner prescribed. Such failures are due, of course, to those temporary aberrations which, for want of more knowledge, we call absence of mind, but which seem inseparable from human existence. Carelessness, in the sense of deviation from regulations, there may be, but it should not be forgotten that men necessarily have other interests, other causes for thought, and that those most capable of concentrating their attention are always more or less conscious of other thoughts obtruding on their notice.

The object in contrasting the Board of Trade requirements with regard to interlocking with the less onerous stipulations for the electrical apparatus, is not to suggest that similar requirements should be imposed with regard to the latter. As a matter of fact, the railway companies have, generally speaking, been much in advance of their obligations, as will be seen when it is stated that, whilst the Act of Parliament making the block compulsory is dated 1889, and the requirements of the Board of Trade with reference to the Act are dated 1892, the decade during which the greatest progress was made in installing

the block was that of the seventies. Railway companies have spent enormous sums in equipping their lines with signalling apparatus, which, from the operating point of view, works well on the whole, and which, by the high degree of certainty that it introduces, has also contributed largely to speedy transit. Naturally, before scrapping their present apparatus and incurring the enormous expense which such a course would involve, they desire to assure themselves that any suggested change of procedure will have the advantages claimed for it. A well-known American signalling engineer some time ago said that absolute safety could only be assured by building a track for each train operated. The most rabid perfectionist would hardly desire to push his requirements so far as absolute safety if it is to be obtained at such a cost. Perhaps the American gentleman only desired to indicate that "absolute" perfection is unattainable.

Lock and Block.

The system of signalling considered is the manually operated and manually controlled, and its limitations have been referred to at some length. We may now briefly consider what suggestions are available for reducing the risks which experience shows have to be run from failure of the controllers. Generally, such systems are known by the not very appropriate or self-descriptive name of "lock and block," and they have as their object the union of the mechanical signals with the block apparatus, so as to make their operation interdependent, as far as consideration of the conditions obtaining may seem desirable. In this country systems have been devised, among others, by Sykes, Spagnoletti, Langdon, Saxby and Farmer, Tyer, Evans, and O'Donnell. Such systems, however, form at present but a very small fraction of the signalling apparatus in this country.

We have seen that the signalman at the entrance to a section may, with the ordinary system, send a train away without the concurrence or even the knowledge of the signalman at the exit. In order to prevent this, the signal controlling the entrance to a section is so interlocked with the block instrument at that end that it cannot be lowered to admit a train unless the man at the exit has given "Line clear," and so accepted responsibility. We know also that after sending a train away the signalman at the entrance may neglect to replace his signals to danger, and so, under certain circumstances, admit a following train. To prevent this, a complete lock-and-block system provides that a train, after passing the signal controlling entrance to the section, shall automatically put that signal to danger, and so protect itself if the signalman neglects to do so. Replacement of the signal lever in the normal position for danger results in it being locked by the block instrument, which prevents it being used again until another "Line clear" signal is given from the exit. We have also noted the fact that, with the ordinary system, the signalman at the exit can give "Train out of section" for one train and "Line clear" for one following, quite irrespective of the actual condition of the section, and before the first train is out. To remedy this the instrument controlling the indications at both cabins is arranged to lock itself by the operation necessary to

give "Line clear." This lock is maintained until the train so signalled has passed the signal controlling entrance to the next section, or has otherwise been disposed of. Hence we see that the operations of the signalman are cyclic, and are intended to be made in a given order. Further, we see that the operations of the signalman are checked on the points where risks of error exist in the uncontrolled systems.

Whilst the union of the signals and block instruments compels, under ordinary circumstances, cyclic operation by the signalmen, it by no means follows that the movements of all classes of traffic is, or can be, made in one unvarying order. Circumstances are constantly arising which necessitate deviation from the simpler routine of a block section, and means have to be provided to meet them. These are obtained by the provision of a "releasing key," by the use of which certain parts of the cycle necessary under ordinary conditions may be anticipated or dispensed with. The importance attached to the use of the release key may be gauged from the rules relating to its use for "cancelling," "obstruction danger," and "blocking back" signals, failure of rail contact, etc., and the special caution to signalmen "not to resort to the key until they are quite satisfied that its use is really necessary." Practically speaking, the provision of the releasing key is an acknowledgment of the want of sufficient flexibility to meet such cases as occur in the common operations necessary to the movement of traffic. As such, it is also an infraction of the automatic character of the system, and again saddles the signalman with the responsibility, under the ordinary system, of which it is the object of the lock and block to relieve him. Granted that the automatic character of any apparatus may be infringed for a legitimate purpose, and it ceases to be automatic. If use can be made of such apparatus under conditions that are suitable, there is nothing to prevent its use under misapprehension. If a misapprehension exists with reference to the conditions, no large-lettered cautions will prevent its use, as the signalman will be satisfied of its necessity, and recording use of the key in the train-book will not avert the consequences of the act. Instances have occurred where use of the release key under misapprehension has had serious results. Hence, whilst the lock-and-block is undoubtedly a step in advance of the ordinary system, it cannot be regarded as infallible, since in the use of apparatus provided to meet certain contingencies the signalman must exercise his judgment as to whether the circumstances absolutely warrant the course.

The type of rail treadle used in lock-and-block systems has the grave defect that it will clear a section behind it when under certain circumstances the line may not be clear. Such treadles are actuated to perform the release operation at the starting signal by the first vehicle passing over them, and so may clear a section by the first portion of a train which has become divided. Hence, although the block instrument would be released by the first portion of a train, and may again be used immediately, yet the signalman must personally assure himself that the whole train has passed, as he has to do in non-automatic systems.

In connection with the safety of such a system, we have with certain classes of instruments further to consider the effects that may be produced by contact between the block wire of either instrument and another working wire, and of the effects of atmospheric discharges. It is not the custom to build separate telegraph lines for the block circuits any more than it is not the custom to provide a separate track for each train operated. Line contacts, no doubt, still occur occasionally, and lightning protectors do not always protect.

Fog Signalling, etc.

It will be noted that the lock and block does not provide checks to obviate the consequences of neglect or inadvertence on the part of one of the persons concerned in the movement of traffic—the driver. He is left altogether out of consideration, and must rely upon himself for due observance of the signals exhibited for his guidance. Yet the driver is probably the most important of the persons concerned, since he is the actual controller of the means of movement of traffic, and is the last link in the chain of checks imposed by signalling systems. Whilst accidents have taken place from disregard of signals in clear weather, the duties of drivers are most onerous during fogs or snow-storms, which obscure the sight of the signals by which they are guided. Under such circumstances the visual signals are supplemented by explosive signals directly operated by the passage of trains over them. The detonators, which are placed on the rails in the neighbourhood of the signals by hand, by men specially collected for the purpose when such signalling becomes necessary, are the danger-signals, but they are supplemented by signals with hand lamps, for which the drivers and firemen must watch. The signals themselves are operated by the signalmen in the usual way, and the fog-signalmen act in accordance with the positions of the signals from time to time. Whilst a signal is at danger the detonators must remain on the rails; when the signal is off they are removed. The off position of a signal which cannot be seen is therefore indicated to a driver by the absence of an explosion, and the hand-lamp signals.

Such a system is most expensive to the companies, entails considerable exposure and hardship upon the fog-signalmen, and suffers from defects of a practical character in operation. The collection of the men for fog signalling occupies some time, as they have to be withdrawn from other duties, or to be brought from their homes. The person who has to decide upon the necessity or otherwise of commencing fog signalling is not the person most vitally concerned, or who has effective control of the movement of the traffic affected. Fogs are sometimes of a deceptive character, and appear differently to a man on the foot-plate and another on the ground, and they change in intensity very rapidly on occasion. The "All right" signal is partly of a negative character, in that it is given by the absence of explosion, together with the hand-lamp signals. The latter signals may or may not be seen by a driver or fireman. Sight of such signals involves either continual concentration for the purpose, or the ability to localise positions so as to be able to look specially for them at the proper time.

This question of localisation of position is of some importance. Experienced drivers, of course, know the "feel" of the road perfectly well, and localise their position from a large number of local circumstances, such as the passing of (over and under) bridges, curves, cuttings, signals, cabins, stations, etc., all of which "talk" to them. Whilst this is the case at ordinary speed the indications are not so plain at lower speeds, and, moreover, approximately the same indications may be met with at different parts of a journey. Hence, taking all things into consideration, the present system of fog signalling leaves something to be desired.

Attempts have been made to place the operation of the fog signals in the hands of the signalmen, but whilst such methods enable the system to be brought into use more promptly than when hand signalling is resorted to, and obviate hardship and exposure to the fogmen, it does not alter the character of the signal, and, moreover, it does not allow of personal supervision, and abolishes the supplementary hand signals. Probably the most promising systems for superseding the ordinary fog signalling are those which provide for the signal being given directly upon the engine itself, and for it to be in constant operation. There is quite a large number of such systems available now, but taking the whole country into consideration their adoption is not proceeding at a great rate. Some of the systems referred to are mechanical, such as that devised by Mr. Raven, of the North-Eastern Railway, and which is being fitted to a large number of the company's engines; others are partly mechanical and partly electrical, as Mr. Brierley's system, which has been introduced by Messrs. Saxby and Farmer; others again are wholly electrical, such as the method of signalling devised by Lieutenant-Colonel Bolitho. The majority of such systems operate by means of an obstruction working in conjunction with the signal to be indicated, placed on the line, which gives an alarm on the engine, and so calls attention to the position of the signal, In Mr. Raven's system the alarm is a special whistle which may be operated by steam or compressed air. In Mr. Brierley's and Lieutenant-Colonel Bolitho's systems attention is drawn by means of electric bells and discs, and electric bells, respectively, carried on the engine. In the latter the electrical circuits are closed by contact with steel brushes placed on the line side in a similar way to that previously used by Mr. Burns and others. In some of the systems an alarm when the signal is "on" is considered sufficient; in others, again, provision is made for repeating both the "on" and "off" positions, so that the signal is positive in both cases.

It is, of course, impossible to enter into a detailed description of such systems, or even to enumerate all of them. Mention, however, should be made of the system devised by Mr. W. S. Boult, in which necessity for contact between parts of moving vehicles and obstructions on the line is obviated. This is done by the use of permanent and electro magnets placed on the line, the latter being operated in conjunction with the signals. The magnets act upon polarised relays carried upon the engine in such positions as to pass immediately over the former, and the relays operate appropriate circuits for the purposes

required on the engine. The indications given on the engine are visual (miniature distant and stop signals, and numbered and coloured discs) and aural (bells). The system distinguishes between "on" and "off," between "distant" and "stop" signals, provides route indicators to show on the engine which road has been prepared at junctions, is capable of repeating the signals in the cabins, and is self-testing for both engine and line circuits. Failure of the line or engine circuits also results in the danger signal being given at the next signal approached after the failure, and partial failure of the latter circuits is distinguishable. One special feature of the system lies in the fact that the last indication received on the engine remains until the next signal is reached, and so serves as a continual reminder of the conditions under which the train is running. This result is not obtained with the present system of visual signalling, and its value in a case where a driver has failed to comply with the signals exhibited is obvious, whilst the ability to distinguish between distant and stop signals is a valuable characteristic for purposes of localisation. The indications given upon the engine are of the most positive character, the semaphore arms being first thrown to "danger," after which they either remain in that position if the actual signal is "on," or are immediately lowered if the signal is "off." The system is of the most complete character, and its design shows the closest study of the conditions to be met, whilst the details of the apparatus are most ingenious and at the same time very simple. Its adoption would revolutionise the method of signalling, since practically there would be no necessity for providing the mechanical signals now in use.

The selection of a system of auxiliary signalling such as has been considered has a business aspect, as well as the technical and operative sides. In order to get the utmost value from such a system, it should, since engines run over other companies' lines than their own, be uniform for all lines if possible, or at least for the lines over which interchange of locomotives takes place. Some companies might be able and willing to pay more for the additional security to be obtained than others; and some, again, might consider certain precautions essential which to others might appear to be superfluous, or not worth the cost of obtaining. The matter is one for common agreement amongst the companies running over each other's lines. Otherwise, the subject is likely to prove a worthy successor to the position so long held by proposals to supersede the cord communication by electrical means—a matter for wordy debate to be settled eventually by the adoption of other means.

"AUTOMATIC" SIGNALLING.

Summing up the situation as it appeared to him in 1898, the present speaker wrote: "Railway signalling appears to have now reached a stage at which some departure from the present methods seems probable. The lines upon which changes will be made will, in all probability, result in a greater degree of automatic control than obtains at present." The indications at present seem to confirm this view very strongly, and we appear to be likely to see early changes in

the methods of signalling of the most radical character. The American "track circuit" system is gaining a footing in this country, and if it should be found suitable for a country where junctions are so numerous and near together, and where the great bulk of traffic is between points comparatively near to each other, a revolution will be effected which will at once change the whole character of signalling in this country. And there is no more reason to doubt that the success of such a system will result in financial relief to the companies than there is to doubt the necessity for such relief.

In this country there is already an installation of automatic signalling in operation between Grateley and Andover, on the London and South-Western Railway, in which the signals are actuated by air on the low-pressure system, the movements being controlled by the positions of trains on the line, which is formed into track circuits. The North-Eastern Railway Company has also made arrangements with the Hall Signal Company of America to equip a portion of their main line to the North, between Alne and Thirsk, with a track circuit system of automatic operation. This installation will differ from the ordinary Hall system—in which the signals are operated by electric motors—and from the London and South-Western Company's installation, in that the signals will be self-contained as regards motive power. Movements will be made by carbonic acid contained in steel cylinders at a pressure of 600 lb. per square inch, the working pressure being 50 lb. As many as 10,000 movements can be obtained before it becomes necessary to recharge. At the junctions between Alne and Thirsk the automatic signals leading to fouling points with the branch lines will also be under manual control, so as to admit of branch working. Such cabins, however, will be closed at times when the branch traffic ceases. The sections will be shorter than ordinary. Siding points connecting with the main line in the purely automatic sections will be provided with indicators communicating with several of the rear sections to show whether trains are approaching before the switches are opened for the siding. It is expected that a considerable annual saving in the working expenses for the signalling of that portion of the line will result from the change, and if this is effected and the system is otherwise satisfactory, no doubt further extensions will follow in the near future.

Taken on the whole, railway signalling in the States is of a very mixed character, and varies from the antiquated "train dispatcher" system, with or without telegraphic communication, through the telegraphic, the manually operated, manually controlled, and the controlled manual, to the automatic systems. There is not time here to discuss these systems, or the many other interesting details of American signalling, such as, for instance, the relative advantages of the "normal clear" or "normal danger" positions for signals; two or three position signalling; track sections *versus* treadles for the controlled manual; the simple single signal, the overlap, or the home and distant systems; the operation of signals by electricity or air, and high or low pressure for the latter; track batteries and relays; the bonding and insulating of rails; and other matters of a very practical character. The auto-

matic system seems to have taken firm hold, and when we consider its advantages as looked at in the States, there seems to be little cause for wonder that it has done so, especially in a country where long continuous runs between diverging points are common. The reasoning adopted is very plain, as the following quotations from a series of articles in the *Electrical Review* last year will show: "If the substitution of automatic devices for the control of a system formerly under human control and operation (the controlled manual is being referred to) produced such beneficial results, why, one naturally asks, should not the introduction of automatic mechanisms for its operation produce like benefits." "It"—the automatic system—"is constantly on duty, requires no relief substitute, never goes on strike nor tires of its job, never sleeps, gets drunk, or deserts its pals, and never misconstrues orders." "The ideal system is one in which the train in a block has control of the signals governing the entrance to that block." "The system affords means of detecting misplaced switches in the block, of failure of cars on a side track to stand clear of the running line, has frequently detected broken rails and obstructions in switches, it affords opportunity for trackmen to protect blocks during emergencies, and for protection during repairs." "Operators for such a system are superfluous, and could only be of use in case of derangement." "Railroad officials are universally awakening to the possibilities of automatic signals, and that wages are better utilised in obtaining automatic operation."

Another advantage claimed for the automatic system is that the carrying capacity of a line may be increased from the facility with which the block sections may be shortened. On this subject, however, the last word is not with the signalling systems, since the lengths of the sections must always be such as to allow any train, whatever its speed, weight, and braking power, to be brought to a stand in the space allotted. The suggestion, moreover, involves a levelling of speeds, which again will require limitation of loads for mixed traffic, since the standard of speed will always be set by the fast passenger traffic. There is no tendency ascertainable in either of these directions at present.

Further study of automatic systems shows the great necessity for supplementary signalling under exceptional circumstances, such as fog or snow, since there is no personal supervision. Some form of apparatus giving the signals on the engine would seem to be imperative.

Where automatic signals are in use, the rule that a stop signal shall not be passed when in the danger position unless other signals are given which are recognised as superseding it, must necessarily be abolished, and a time limit of detention at the signal imposed, after observance of which the train goes cautiously forward until ordinary signalling is resumed in the sections ahead. Unless special regulations or provisions are made, and in the event of prolonged operations at a point giving access to the main line, this may result in a train arriving at the signal actually protecting a train drawing on to the main line, when, of course, the space limit will not be observed.

In the States, it is usual to distinguish signals which may be passed at "danger" after a time interval from those which, being under manual control, may not be passed without special instructions. Where signals are at one period automatic and at another under manual control, the conditions are more complex.

Possibilities of Signalling with Electric Traction.

We have seen that the adoption of human control for railway signalling has necessitated the imposition of numerous checks upon the actions of the controllers, and has required considerable auxiliary apparatus for a variety of purposes. The adoption of automatic signals dispenses with all the costly apparatus referred to, except at junctions where, owing to the want of selective properties, automatic systems are unsuitable. The question for consideration now is, "Is the automatic system, as described, final?" If we consider the present outlook with regard to railways, we find that we are probably on the eve of a very great change in methods and even routine of transportation. The great question to be now decided concerns the use of the self-dependent locomotive, or, as an alternative, the use of locomotives taking their power from their locality, wherever that may be, in the line of their run. The question is not entirely confined to steam and electricity, although at present these two are the only ones worth considering. As all are aware, the railway companies are taking action in consequence of the incursion of the electric tram into what has hitherto been practically a monopoly. The directors of the North-Eastern Railway are considering tenders for the equipment of part of their lines in this neighbourhood for the use of electric power; the Lancashire and Yorkshire have partly completed their arrangements; the London and North-Western are said to be considering the question; and the Great Eastern are to apply for powers for the same purpose as early as possible. The proposals now being put forward are for comparatively short-distance suburban traffic; the electrification of long-journey main lines is not just yet.

The point for consideration here, however, is not the suitabilitv or otherwise of electric traction, but the effects that it may have on signalling. If we look over the principal equipments of a train, we find that we have steam for locomotion; gas, oil, or electricity for lighting; and pneumatic appliances for braking. Electricity is capable of displacing all these for each of their several purposes. As electrical power is delivered to the locomotives from the outside, we have presented to us conditions which have no precedent, and opportunities for outside control such as have never before existed. Hitherto the driver has been the sole actual controller of the means of locomotion, and short of throwing the train off the line, or into a dead end, no other person could affect the results when he neglected certain duties. With electricity all this is altered, and we have to deal with an agent which is easily handled, and lends itself readily to automatic or other control and operation. American automatic signalling gives control of the signals to the train requiring their protection. Where

supplementary signalling is in use to check error on the part of the driver, its design is generally with a view to direct action on the control of the motive power, rather than to call attention to a dereliction of duty, as with us. With electric traction there should be no difficulty in arranging to give such direct control to the train which requires to be protected by cutting off the power from all sections that would endanger its course, whether these are "following," "converging," or "crossing." Signals as now used would then be superfluous, except at such places as those where selection of traffic rendered them necessary. Control of the motive power is a far more effective check on inadvertence than any other that can be devised. The whole aim of the signalling now in use on railways is to control the man who controls the motive power. If we can give to a train the means of controlling the motive power to other trains, which may be sources of danger to it, the men who control the motive power on those trains will no longer count in connection with the subject under notice. After all, automatic signalling, as described, does no more for the driver than the manual or the controlled manual, if as much, since it removes the personal supervision now provided, which is not *always* faulty, and has on many occasions been of the highest possible value.

The author's thanks are due to Mr. Raven, of the locomotive department, and Mr. Ellison, the superintendent of the telegraph department of the North-Eastern Railway, and to Mr. Fletcher of the L. and N.W. Railway, for the loan of apparatus for use at the meeting.

Mr. Heaviside. Mr. A. W. HEAVISIDE said that, with regard to Mr. Pigg's paper on "Railway Block Signalling," they were certainly obliged for such an exhaustive statement of what is done in this direction at the present time, which is a very critical one in the history of block signalling. He was one of a party which recently visited Tyne Dock to see the system in operation there, and it occurred to him that the capital cost was very considerable—rather more than the ordinary system. He did not see why they should not do the whole thing electrically, and not use pneumatic power at all. If a man were to commence to build a new railway at the present time, he did not think it likely that he would proceed on the same methods as the existing arrangements. The old system requires a great deal of maintenance. Mr. Pigg had said that the North-Eastern Railway Company had employed the telegraph and the telephone as an auxiliary, and he would be very glad to hear more about his experiences with the telephone. There were many other interesting questions which might be raised, but in the absence of Mr. Pigg it was rather difficult to carry the discussion much further.

Mr. Moir. Mr. A. MOIR said that, while asking for more seemed rather ungracious, seeing the paper was so long and exhaustive, if Mr. Pigg had been there he would have liked to have asked him what the resistance of the block coils is which they use on the North-Eastern Railway, how many amperes were required to actuate the instruments, what sort of primary battery did they find gave best results; also whether secondary cells have been employed with any success

Mr. R. M. LONGMAN: With reference to Mr. Pigg's statement that no passengers lost their lives in 1901, it may be added that many fatal accidents occurred at highway level crossings, due in many cases to carelessness or forgetfulness on the part of the gatemen, who often open their gates without placing their signals against the trains. A little interlocking device would thus save many lives. **Mr. Longman.**

Mr. J. PIGG (*in reply, communicated*): I regret that a misunderstanding and my recovery from an illness led to my absence from the meeting of January 19th and have further prevented a full discussion of the problems to be met with in railway signalling. There can be little doubt, as remarked by Mr. Heaviside, that the capital expenditure for such a system as he inspected is greater than that for the ordinary system; but if a commensurate saving is effected, either in labour or by facilitating the operation of traffic, the increased expenditure will be justified. Whether such a saving will be shown remains to be seen. The period of use is at present too short to enable a reliable opinion to be formed. It must, moreover, be remembered that the maximum economy is not to be expected from such a system in small isolated installations with separate equipments for motive power. **Mr. Pigg.**

The employment of the telegraph and telephone in connection with the operation of railway traffic is, as stated, auxiliary to the ordinary block signalling, and does not differ materially from the methods of using such instruments elsewhere. They are not used *directly* in block signalling, but for perfecting arrangements before traffic is allowed on the line, or for giving information beyond the scope of the code, or for communication between block points not directly connected for signalling purposes. The telegraph is used for transmitting notice of the times trains leave or pass certain points to other places on their routes, so that proper arrangements can be made for dealing with them without unnecessary delay to other traffic. The telephone is used for similar purposes, but more locally and over less extended distances; although valuable auxiliaries for the working of traffic, they are not, of course, part of the block system proper.

With reference to Mr. Moir's questions, the block indicators in use on the North-Eastern Railway are wound to a resistance of about 150 ohms. The batteries used are the ordinary porous-pot Leclanché cells. A six-cell battery is used for the pinning instruments, and a four-cell set for the non-pinning. (Since the reading of the paper the North-Eastern Railway has ceased to use the block indicators in connection with the code, and no doubt the non-pin batteries will be dispensed with.) I have no idea of the minimum current required by the block indicators. On the North-Eastern Railway they work perfectly well with ten milliamperes, but they are never intentionally worked with the minimum.

Secondary cells have not, to the writer's knowledge, been tried anywhere for block working, and the prospect of their adoption does not seem very great. The first cost and maintenance of such cells would seem to be necessarily greater than that of primary cells, and the amount of apparatus in the average signal cabin hardly calls for the adoption of the universal battery system which the use of storage cells

Mr. Pigg. so greatly facilitates. Moreover, such a battery arrangement is for railway signalling an operation of the nature of putting too many eggs in one basket. It is desirable that the signalling of the different lines should be as independent as the lines themselves are for the operation of traffic.

There is a certain amount of truth in Mr. Longman's remarks respecting accidents at gate crossings. Accidents do occasionally occur at such places, but although the writer has mixed intimately with gatemen over a considerable area of this country, and although he pays great attention to the reports of the inspectors of the Board of Trade, he would not go so far as to say that they *often* open their gates without placing their signals against the trains. There are many cases in the writer's own knowledge where signal cabins are erected at highway crossings solely on account of the traffic on the road. In these and in all cases where the gates and signals are worked from one point the gate-wheel is interlocked with the signal levers. In others cases a dwarf frame is provided which affords the interlocking referred to. At gate crossings between block points many companies provide electrical apparatus, connected in the block circuits passing the gates, by which the gateman is constantly aware of the condition of the line on both sides of his gates.

LEEDS LOCAL SECTION.

MOTIVE POWER SUPPLY FROM CENTRAL STATIONS.

By R. A. CHATTOCK, Member.

(Paper read at Meeting of Section, February 19th, 1903.)

The development of a supply of electric energy for motive power to private consumers has been occupying the attention of Central Station Engineers for a considerable time, and, during the last two or three years, has been stimulated very much by the excellent results that have been obtained in several large towns. It is obvious that, given a large network of mains that has been laid for the purpose of supplying lighting consumers, it is to the interest of these consumers, as well as of the authority responsible for the supply, to have as much current as possible distributed through it, especially during the hours of daylight. The lighting consumer benefits by the greater output combined with the increased load-factor at the generating station, making it possible to generate current at a cheaper rate. The supply authority benefits by being able to reduce the cost of supply and by having the demand for current stimulated. The standing charges on the cost of the mains are spread over a greater output and so reduced proportionately.

Direct-current stations, so far, have done most in developing this branch of the supply. This is probably because the direct-current motor has, up to recent times, been more easily applied to existing conditions, and has proved a more reliable and efficient machine than the single-phase alternating-current motor. Now that alternating-current stations are changing over to, or putting down, auxiliary, two- and three-phase plant, this disadvantage should disappear, and the engineer in charge of such a station should be able to follow in the steps of his direct-current brother.

It may be interesting to give a short description of what has been done in connection with a supply of current, for motive power, by the Corporation of the City of Bradford. The supply is by means of direct-current, the voltage being 230 or 460. The first motor was connected to the mains in 1891. There was not much development until 1897, when the Corporation inaugurated a system of hiring out motors, and at the same time reduced the price for current to 2½d. per unit. In 1896 the percentage of current sold for motive power to the total output was only 6·7 per cent. This percentage has rapidly increased as the facilities provided for obtaining motors have been realised and appreciated by the public, and as the charge for current has been reduced to the existing rates of 2d. for intermittent use, and 1d. for continuous use, until, in 1902, it stood at 49·25 per cent.

The gradual increase in this branch of the supply is set forth in the following table, which also shows the improved load-factor of the generating station.

	Year.			
	1893.	1896.	1901.	1902.*
Motors on the Supply, Dec. 31st. On Hire	—	7	525	641
Motors on the Supply, Dec. 31st. Not on Hire	26	58	229	272
Motors on the Supply, Dec. 31st. B.H.P. ...	110	244	3,460	4,398
Units sold for Motive Power	19,346	54,972	1,297,120	1,899,873
Total Units sold to Private Consumers	480,494	813,623	3,012,158	3,857,757
Percentage of Motor Units on Total Units...	4·02	6·76	43·06	49·25
Price charged per Unit for Motive Power...	4½d.	3½d.	2d. & 1d.	2d. & 1d.
Average Price per Unit obtained for Motive Power	4·5d.	3·5d.	1·20d.	1·17d.
Load Factor, excluding Traction, per cent.	3·13	8·93	11·74	13·78

* The figures for 1902 are approximately correct.

During these years it has been possible to reduce the charge per unit for current supplied to the lighting consumers from 6d., in 1892, to 4½d., less 2½ per cent. discount and a free supply of incandescent lamps, in 1899. The price has stood at this figure up to the present date, but the Corporation anticipate that they will be able to reduce it still further in the near future.

In calculating the cost of generation of a motive power supply, when this is combined with a lighting supply, the following points must be borne in mind:—It is not necessary to increase the staff of men employed in the station beyond what would be required for a pure lighting supply. The management expenses, rents, rates, and taxes remain the same. The plant installed in the generating station has to be increased only very slightly, owing to the fact that the main part of the motive power supply is discontinued at 5 p.m., before the peak of the lighting load has to be met; the part that does overlap, can be safely and most economically dealt with, by slightly overloading the station plant, for half an hour a day, for about six weeks during the twelve months. The question of black fogs, of a density sufficient to necessitate a supply during the hours of daylight, equal to the maximum lighting load, has very rarely to be considered, so rarely that it really only affects one or two towns in the country. A fog such as is ordinarily met with will not create a demand for more than 75 per cent. of the maximum lighting load, and it is found in practice that the motive power supply can be satisfactorily dealt with by the plant installed.

The same considerations apply to the question of extending the distributing network of mains. It is found that the majority of motors installed, are connected to the existing network, which has been laid for the supply of lighting consumers, and the current used by these motors helps to utilise the mains during the hours of daylight. This is a set-off against any small extensions that it may be necessary to make to supply outlying power consumers. In some cases, however, considerable extensions may be necessary; these should be considered separately, and if the estimated revenue from the current supplied does

not equal a certain percentage on the cost of the extension, the application should not be entertained, unless, of course, the applicant is willing to pay such a sum towards the cost of the extension, as will make it remunerative.

The minimum percentage on the cost of an extension, that it is policy to require, must be different in different towns, and can only be ascertained by experience. As a basis to go upon, a percentage of 10 per cent. is suggested, this figure having worked out satisfactorily as regards the City of Bradford.

It may be safely assumed, therefore, that the cost of generation should not be estimated to include the following items :—

Wages in Generating Station.
Management, rents, rates, and taxes.
Standing charges upon the outlay in respect of station plant and distributing mains.

The items which should be included are as follows, and these should be taken at the full rate per unit for the whole of the supply :—

Coal.
Water.
Oil, stores, etc.
Repairs and maintenance of plant and mains.

Turning now to the considerations affecting the price to be charged. It has, during the last four years, been the practice in Bradford to charge one penny per unit for motors used continuously throughout the working hours of the day, and twopence per unit for those used intermittently. This method of charging has answered fairly well, though it is open to several objections. For instance, some power customers who use their motors intermittently consume a much greater number of units per horse-power installed than others who have motors running continuously ; again, it is often very difficult to decide whether the use of a motor is intermittent or continuous.

The maximum demand system of charging is not so applicable to motor supply as it is to lighting supply, on account of the fluctuating nature of the load on a motor, and of the liability to sudden heavy overloads. The effect of these overloads is not necessarily felt by the generating station at the peak load time, but the reverse of this is rather the case.

It would seem that the best method of charging is to base a sliding scale charge per unit upon the number of units used per horse-power installed per half year. Such charge might be graduated at 1d., 1½d., 2d., and 2½d.

It is found that compared with a gas engine using gas at 2s. 3d. per 1,000 cb. ft., the cost of running a motor at 1d. per unit is considerably less, in some cases the cost is half that of gas, in others the cost is approximately the same. This, however, is owing to the motor being set to drive long lengths of shafting where the load is fairly continuous and heavy, an ideal drive for a gas engine. Where the load is subject to great fluctuations, as is the case with crane and hoist driving, the

motor, even at 2d. per unit, shows a great saving over the gas engine. This is owing to the facility for stopping the motor when not actually in use, and starting again when required. It is found that this cannot conveniently be done with a gas engine.

In order, therefore, to show a saving over gas at the above figure per 1,000 cb. ft., the charge for current should vary from 1d. to 2d. per unit.

The amount charged for rental should be kept as small as possible consistent with paying actual expenses, and any profits required should be looked for from the sale of current and not from the receipts for rental.

The rental should include the following items: –

Interest upon capital cost of motors and other apparatus.
Cost of inspecting motors periodically.
Cost of maintenance of motors due to fair wear and tear.
Cost of depreciation on motors.

In the City of Bradford, for the year 1902, the cost of inspection and maintenance of motors on hire amounted to £1,723, the H.P. of the motors on hire being 2,996.

It would appear that an amount of 15 per cent. on the capital cost of apparatus is sufficient to cover all liabilities in connection with a hiring out department, and to allow sufficient margin for depreciation.

In conclusion, it is hoped that the figures and suggestions given in this paper may be of interest to Central Station Engineers. They are based upon actual experience in connection with the Bradford Corporation supply, and should prove useful, especially to those Engineers who are contemplating a motor-hiring department.

Mr. Mountain.

Mr. A. B. MOUNTAIN said that he agreed almost entirely with Mr. Chattock. He was of opinion that a supply of 4,398 H.P. for motors was larger than the supply in any other town in England, and the author would no doubt say that the great success at Bradford was due to the fact that this city had a large number of small trades.

Regarding the single-phase question the speaker thought that Mr. Chattock was a little late in his criticism; if he had made this remark three years ago most people would no doubt have agreed with him. In England there were about one thousand manufacturers of continuous-current motors, but few of them make single-phase, and, probably, fewer still two- or three-phase motors. There were thousands of persons criticising single-phase motors and advertising continuous-current, but he did not think that it was wise for them to allow themselves to be carried away. They had, rather, to think of what was really right and suitable. He disagreed with Mr. Chattock on this point very strongly.

Referring to the percentage (10 per cent.) allowed by Mr. Chattock on the cost of an extension, he thought that there must have been an oversight here. He did not consider that 10 per cent. would cover the cost of the extension for mains, unless, of course, there were very special consumers.

Further, he did not think that the author had sufficiently brought out the great advantage of electric motors over gas engines. There was no doubt that, by getting rid of shafting, the power required in a place was enormously reduced. For example: In a small works that he recently visited they used to have a gas engine of 16 H.P., but they now find that five H.P. in motors put on different machines would do precisely the same work. Mr. Mountain.

Mr. G. WILKINSON said Bradford was a pioneer town in electric lighting and certainly showed the way in promoting the sale of electricity. Like the previous speaker, he was very much struck with the second paragraph of the paper. It showed that Mr. Chattock had a certain amount of pity for the community which has to put up with single-phase motors. He himself did not share that sentiment. In the first place he would like to point out how very much more reliable they were than direct-current motors. Taking into consideration the fact that the revolving part simply consisted of a mass of iron with short-circuited conductors, the advantage certainly rested with the single-phase machines so far as reliability was concerned. The great drawback at present, admittedly, was the want of a simple method of varying the speed of single-phase motors. He had used this type for hoists, cranes, printing machinery, and the like, and had found them very successful. Mr. Wilkinson.

Mr. Chattock had stated that the load factor in Bradford, excluding traction, was 13·78. He presumed that this did not represent power, but was simply the load factor relative to the motor business. From the amount of the horse-power supplied, he thought that in Bradford many of the motors were small.

Concerning the supply of electricity for large powers except for intermittent work, there was a very formidable rival in oil engines. Mr. Chattock gave a comparison between electricity at 1d. per unit and gas at 2s. 3d. per 1,000 cubic feet, but he did not mention anything less than 1d. per unit for electricity. There were English oil engines made which would give 5 or 6 H.P. for an hour for 1d., and there were German engines, one of which he had under his control, working daily for practically 16 hours, giving 9 B.H.P. for 1d. per hour. They required a certain amount of labour and attention, but they had many advantages. In the future we should have very keen competition from oil engines. There were now firms ready to enter into contracts to supply any quantity of oil as fuel at 35s. a ton.

With reference to the extension of mains in Bradford it appeared that the charge was upon a basis of 10 per cent. on the capital outlay. The paper did not indicate whether this was an annual charge or whether it would run out when the interest and sinking fund expires. It seemed to be a very reasonable figure, but further information was desirable. Again, consumers who used their motors intermittently appear to consume a much greater number of units than did regular users, and it appeared that they must therefore have motors too large for the work they have to do.

He quite agreed with the sliding-scale method as an equitable means of charging for power, and was quite gratified to find that 15 per cent. was sufficient to cover the cost of a hiring-out depart-

Mr. Wilkinson. ment, and thought it very reasonable and a charge that any consumer could afford to pay.

Mr. Fedden. Mr. S. E. FEDDEN said that he could join issue with the author in regard to single-phase motors. He had installed motors up to 80 and 90 H.P., and lately one of 160 H.P., although he thought it most likely that two-phase motors would be necessary for heavy work. He had, however, no intention of abandoning single-phase working altogether for small motors on present single-phase mains.

With regard to the question of variable speed he had never found any demand for it.

They were in Sheffield following on much the same lines as in Bradford, as they had in 1900 only 20 motors; in 1901, 71; in 1902, 109; whilst this year they had 220, which amounted in all to 1,400 H.P.

With regard to the price of energy, they had always had in Sheffield a charge of 4d. a unit for lighting. Three years ago it was 2d. a unit for power, and they then offered consumers 1½d. per unit, but nobody would look at it. Finally they arranged to charge all-day consumers 1¼d. per unit, with a 1d. per unit for all-day-and-night consumers. If they used sufficient units to make up 50 per cent. of the horse-power installed, they allowed them to come in at the 1¼d. rate. Gas being only 1s. 6d. per 1,000 cubic feet, they had very keen competition.

He encouraged the laying of mains, but did not put on any price or percentage, for the reason that the local price of gas was so low, and their mains were past most of the houses and works. Referring to the cost of generation, Mr. Chattock stated that rates and taxes should not be included, but he thought that a certain percentage of these charges, and also some standing charge on the distribution of the mains, should be added to the cost of the unit in addition to the items mentioned. He was rather surprised to see the figure given for the maintenance of motors. The cost of maintenance appeared to work out at about 11s. 6d. per H.P. in Bradford. The motors averaged 4·7 H.P. each. The cost of maintenance and inspection in Sheffield came to £75 for the whole of the motors, or about 3s. per H.P.

He had not yet had the pleasure of a burnt-out armature, but was looking forward to it.

Mr. Churton. Mr. T. H. CHURTON said that he had had an opportunity of making a comparison of electric driving and gas-engine driving. In his works he had a 6-H.P. Crossley engine and found that, at full-load, the cost was little less than ½d. per H.P. hour, and at normal working load it was about 1d. per H.P. hour. It was necessary, with a gas engine where there was a variable load, to have an engine of considerably greater power than was generally used, but in the case of a motor it was not so. If a gas engine were overloaded it would pull up, but a motor could be overloaded to a very much greater extent, before it will stop, especially if it were a two- or three-phase machine. In his case a two-phase motor was actually costing him less than the gas-engine did, although gas in Leeds cost only 2s. 3d. per 1,000 cubic feet. Unfortunately there was no convenient way of starting single-phase motors, and a method of starting was required which gave really no trouble.

As touching the competition between electric driving and oil engines, it must be noted that motors could be placed where it would be impossible to fix an oil-engine and there was also too much work involved in the use of oil engines, to say nothing of the smell and noise. Mr. Churton.

Mr. V. A. FYNN thought the single-phase motors were not entirely satisfactory. He had been familiar with them since 1893, when they came out, and although he liked them, and was greatly interested in their working, he did not think that they answered the present requirements. In cases where only a few small motors were connected to the supply mains, the power-factor question did not matter very much. If, however, one were concerned with large powers, the matter became more serious than was generally believed. At the Frankfort Exhibition of 1891 a motor was actually shown which had a power-factor equal to unity, although nobody seemed to have taken any notice of it. The principle which was used in that motor he had lately employed with various alterations and improvements in order to obtain a power-factor equal to unity in a single-phase motor of his design which he was bringing out, and which besides having a very great starting torque, gave promise of the possibility of regulating its speed. A 3 B.H.P experimental motor had been completed which started with a 10½ H.P. torque and with a current simply proportional to the full-load starting current. Mr. Fynn.

Mr. W. EMMOTT said that Bradford had been worked for all it was worth with regard to motors. He could not speak from the Municipal Engineer's point of view, but only from that of the Consulting Engineer, and he thought it was a good lesson for some of the smaller stations. Much depended upon the kind of man who was in charge of a motor department. He considered that with a gas-engine running up to 10 or 12 H.P. it was cheaper to put in motors at 2d. per unit. He also thought that 15 per cent. was a large amount for maintenance. For himself he thought 12 per cent. a fair and ample amount. He gave some tests of the low thermal efficiencies of gas in various towns which he had experienced, but as the gas companies were under no obligation to supply gas for power purposes, the consumer had no remedy. This accounted for the large gas consumption per B.H.P. which he had noted in many cases, and was all in favour of electro-motors. Mr. Emmott.

Mr. W. M. ROGERSON thought that consumers using lifts and cranes intermittently, say not more than half an hour at a time, should pay more than consumers using power continuously. Mr. Rogerson.

Mr. H. DICKINSON (*Chairman*) did not agree with Mr. Chattock that it was unnecessary to increase the staff or plant for the full load. If the overlapping motor-load grew larger than the lighting load, he would have to put in additional plant to keep up with it, and consequently the staff would have to be increased accordingly. Mr. Dickinson.

Regarding the extension of mains, on a basis of 10 per cent. of the revenue he thought this very small, and remarked that he would go into some districts for one per cent., but not into others for ten per cent. if there were no prospects; therefore some little reservation was necessary on that point. The consumers around the Works were made

Mr. Dickinson.

equal to consumers in the outlying districts, unless there were a very big margin between the selling prices. At Leeds they were selling at cost price, as, last year, on a capital of £500,000, they made a profit of only £3,000. He did not think he could afford to run to outlying districts on a bare 10 per cent.

Referring to the units per B.H.P. for last year at Bradford, which worked out at about 450 for every H.P. installed, he should like to ask what sort of users they had, because these figures did not at all correspond with those for Leeds. It was there found that they were getting 800 units per H.P. installed. He did not know whether these motors were for hoists, but he thought that Leeds seemed to be in a very favourable position. In 1901 there were 205 H.P. installed; 1902, 685 H.P.; and there were now 1,363 H.P. The price in 1901 was 2d., less 5 per cent., and in 1902 it was 2d. to 1⅛d. on a varying scale. If the units were less then 360 per H.P. it was 2d., and on to 720 units per H.P. installed. The average price obtained for motors was 1¼d.

There were another 400 H.P. awaiting connection, and an application for 500 H.P. to drive a rolling mill had been received.

Mr. Chattock.

Mr. R. A. Chattock, in reply, said that he had not had much experience recently with single-phase motors, but he had had a good deal some time ago. He thought that the motors ran at a very excessive speed, owing possibly to the high frequency that was in general use, and that the efficiency of the motors up to about 10 H.P. was nothing like that which could be obtained from direct-current motors. Commonly the starting current was excessive, and affected the general supply in the neighbourhood, which was a very great objection.

He was surprised to hear that Mr. Fynn and Mr. Fedden thought that there were single-phase motors which would beat direct-current motors.

The phenomenal increase in Bradford was not due to any special advantages; Bradford was an ordinary city, although there were many trades in it. Power was mostly used for crane and hoist work, 4½ and 7 H.P. being the sizes commonly used. There were also a number of larger motors (one of 60 H.P.) driving various classes of machinery, printing works, large ventilating fans and refrigerating machinery. In many cases these motors had been put in to replace gas engines, and the reports of the saving in cost had been most satisfactory.

Referring to the amount of 10 per cent. on the cost of the mains, this amount represented the actual revenue that should be received from a proposed consumer, in order to make it worth while incurring the cost of the necessary mains. If the amount per annum received from the consumer equalled 10 per cent. on the cost of the mains necessary to supply him, he considered that for any ordinary extensions it was policy to connect up.

He agreed with Mr. Dickinson that for very long extensions in outlying districts this amount should be carefully considered, and very probably increased. In fact, he thought that, in getting out the cost for each year, care should be taken to watch that figure and see that the general percentage of revenue to the cost of the mains was not getting too small. If it had a tendency to decrease, then the 10 per cent. should be increased in conformity with the general revenue.

Mr. Chattock.

As regards the cost of steam power, as compared with electric power, he thought that from 150 to 200 H.P. could be more economically supplied by the consumer himself than by purchasing current from a central station, that is to say, as long as such power was used continuously throughout the working hours of the day. An engine of 200 H.P. was as economical as a very much larger engine in a generating station, and there were no distributing charges to face in connection with the steam supply. There was a charge for labour in connection with the running of the steam plant, but from information he had received from mill-owners who had gone into the question, there was no doubt that they could produce steam as cheaply as electricity could be supplied at 1d. from a central station.

With reference to the remarks on the load factor given, it included the lighting consumer as well as the private power consumers, but it did not include the power for tramways, although this came from the same station.

Most of the motors ranged from 1 to 10 H.P. There were 15, 20, and 60 H.P. motors in use, and there appeared to be an increasing demand for the larger size of motor, as they were slightly more economical.

He was very much interested in Mr. Wilkinson's remarks on oil-engines, viz., that 5 or 6 H.P. could be obtained for 1d. an hour. He took it that this was at full load, and that the cost of running an oil-engine at a reduced load would be considerably more. The great objection to oil-engines was the trouble in starting them and their objection to be considerably overloaded, which was a special point in favour of a motor supply. He also believed that Insurance Companies objected to the storing of a large quantity of oil, and there had been trouble in this respect. He thought that if oil-engines came into general use the price of oil would go up. Some time ago he was trying some oil fuel, and from the figures that were worked out he was satisfied that with oil at 2d. per gallon he could equal coal at about 18s. to 19s. per ton.

With reference to the question of continuous users of electricity using less current than those using it intermittently, this was quite possible. The continuous user very often ran his motor for many hours in order to get it at 1d., because if he stopped his motor he was charged at the rate of 2d. per unit. He thought it was best to base a sliding-scale charge on the number of units used per H.P. installed.

With regard to variable speed, he had not found any great demand for it. Possibly they had twenty or thirty motors, varying in size, in which this had been asked for and obtained, chiefly for running special machinery.

He did not agree that the cost of generation should include a portion of the rents, rates and taxes, and a charge on the mains, although that point should be watched. If the supply for motive-power purposes very much exceeded the supply for lighting, the cost of generation should be reckoned out to include more of the standing charges on the station and possibly on the mains, but as pointed out the motor overlap load was apparently very small at present, and in spite of the large

Mr. Chattock.

increase in the number of motors, it did not appear that this should be taken into account for some considerable time.

The figure that was quoted for the maintenance of the motors, viz., £1,723, looked rather high, but it included many spare parts, and also the supply of oil for running and general repairs, the cost of which was refunded by the hirer. It was really men's wages for inspecting and repairing the motors. The wages that were paid for inspection were higher than was the case in many towns, and it was looked upon rather in the form of an insurance. Every motor was inspected at least every two months, and most of them once a month. He thought that the benefit of it would be felt as time went on in the greater life of the motors, because if they were left to look after themselves they were liable to become very dirty. The consumer would not look after them, and he admitted that the commutators were a source of trouble if the motors were not looked after, consequently he did not think it a very heavy item. He thought it would pay the alternating-current consumer to look after his motors and to inspect them more frequently. Time would show if this amount could be reduced by giving up inspecting them so often, but at present he did not feel inclined to run the risk of doing so.

Mr. Emmott thought 15 per cent. on the capital cost of the apparatus was too great an amount to charge, and he recommended 12 per cent. He (the speaker), however, thought that the 15 per cent. charge should be made. The cost of motors during the last four years had dropped by about 30 per cent., and if the charge were 12 per cent. it certainly would not pay for the necessary inspection.

With reference to Sheffield beating Bradford he should be very pleased if they got ahead, but he thought that if the question of the H.P. installed per 1,000 of population were taken into consideration, Bradford would still be able to keep the lead, although the increase was not so great during the last two years. The increase in Sheffield was rather phenomenal on account of the supply being specially pushed just now. At the first everybody was coming on. Directly people began to see that the motors could be obtained cheaply and were doing well, they would all come on in a rush, and in a large town where there was a great amount of power undoubtedly this rush would be felt at first.

In Leeds, Mr. Dickinson said, they were getting 800 units per H.P. installed. In Bradford, however, there were not many motors running on a very heavy continuous load, the work being intermittent and chiefly used in crane and hoist work. The staple trade in Bradford was woollen, and all the mills had their own steam plant. There were not at the present time any motors in use for driving looms or wool-combing machinery. It was found that the people applied for motors for driving cranes and all small machinery where the load was intermittent, and there was no doubt that this accounted for the small number of units that were used per H.P. installed.

ORIGINAL COMMUNICATION.

MEAN HORIZONTAL AND MEAN SPHERICAL CANDLE-POWER.

By ALEXANDER RUSSELL, M.A., Member.

The accurate rating of glow lamps, Nernst lamps, and arc lamps is a matter of considerable commercial importance, and so the following remarks on the mathematics of the question may not be out of place in the Journal. The physical side of the problem, namely, the quality of the light emitted and the best standards to use in the various cases, has not been touched upon.

English manufacturers as a rule do not guarantee that an 8-candle-power glow lamp gives a mean horizontal candle-power equal to eight candles, but merely that the mean horizontal candle-power is within 20 per cent. or so of eight. They do, however, guarantee a certain efficiency with particular classes of lamps, saying for example that their efficiency at the start is 3·5 watts per candle, and that after a thousand hours it is about 5 watts per candle. This method of rating lamps is to be commended, as it cheapens the cost of production and is quite fair to the consumer. By the candle-power of the lamp is meant the mean candle-power in a plane perpendicular to its axis, and this candle-power is also called its mean horizontal candle-power.

MEAN HORIZONTAL CANDLE-POWER.

If from a source S we draw lines equally in all directions in a plane and make their lengths equal to the candle-power in these directions, then the sum of all these lengths divided by their number gives the mean candle-power in that plane. When the axis of the lamp is vertical, the mean candle-power in the horizontal plane is called the mean horizontal candle-power. Now many inventors have tried to increase the mean candle-power in particular planes by means of reflectors and refractors, and some even think that they can increase the total quantity of light given out by the lamp by this means. As a proof they mention that they have increased the *area* of the candle-power curve in particular planes. This they have undoubtedly done in certain cases, but it does not follow that they have increased the mean candle-power in these planes. In fact, when we remember that by doubling the intensity of the source we can quadruple the area of the candle-power curve, the fallacy of their reasoning is apparent. The following mathematical examples illustrate how the area and the mean value of the radius of the candle-power curve can vary in certain cases.

If I be the mean value of radii $r_1, r_2, \ldots r_n$ drawn at equal angular intervals in a plane, then—

$$I = \frac{r_1 + r_2 + r_3 + \ldots + r_n}{n}$$

$$= \frac{r_1\, d\theta + r_2\, d\theta + \ldots + r_n\, d\theta}{n\, d\theta}$$

$$= \frac{\int_0^{2\pi} r\, d\theta}{2\pi}$$

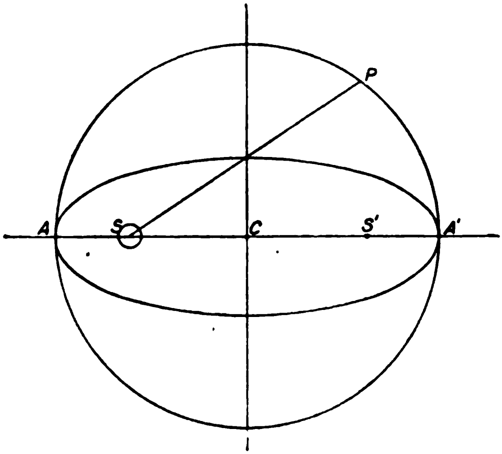


FIG. 1.—*S* is a source of light surrounded by an unevenly distributing globe which makes the candle-power curve in the plane of the paper the circle *A P A'*. Any radius vector like *S P* gives the candle-power in that direction.

$$\text{Mean candle-power} = \frac{\text{circumference of ellipse}}{2\pi}.$$

Now, suppose the candle-power curve to be a circle (Fig. 1), and let S, the source, be any point within it. We may suppose, for example, that the source is surounded by an absorbing cylindrical globe of varying thickness so that the candle-power in the direction S P is represented by S P, and that the locus of P is a circle. We shall find an expression for the mean candle-power for different positions of S, supposing always that the candle-power curve remains the same circle.

If $SP = r$ (Fig. 1), $P\hat{S}A' = \theta$, $CS = a$, and $CA = R$, it is easy to show that—

$$r = a \cos\theta + \sqrt{R^2 - a^2 \sin^2\theta}.$$

$$\text{Hence} \quad I = \frac{\int_0^{2\pi} r\, d\theta}{2\pi}$$

$$= \frac{\int_0^{2\pi} \sqrt{R^2 - a^2 \sin^2\theta}\, d\theta}{2\pi}$$

$$= \frac{\text{circumference of ellipse}}{2\pi}.$$

Where the ellipse (Fig. 1) has S for its focus and touches the circle at A and A'.

When S is at A,

$$I = \frac{2}{\pi} \cdot CA$$
$$= 0{\cdot}637 \cdot CA,$$

and when S is at C

$$I = CA.$$

Hence, although the candle-power curves have all the same area, yet the mean candle-power diminishes as S moves from C to A by about 36 per cent.

It is easy to see from the mathematical definition of mean candle-power that all curves of the family $r = a + b\,f(\theta)$, where $\int_0^{2\pi} f(\theta) = 0$, have "$a$" for their mean candle-power.

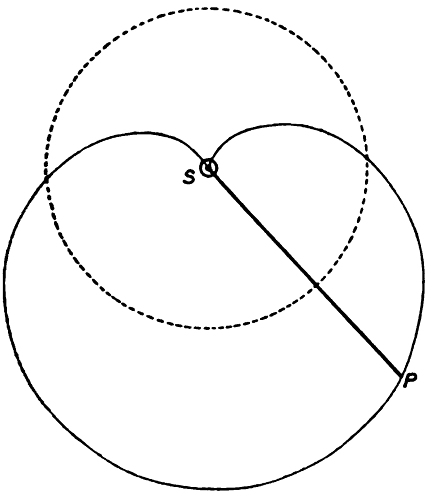


FIG. 2.—S is the source of light, and $S\,P$ gives the candle-power in the direction $S\,P$. Mean candle-power in the plane of the paper equals the radius of the dotted circle.

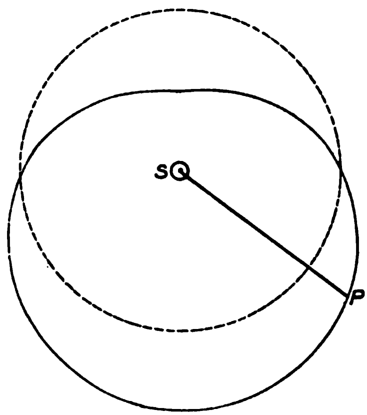


FIG. 3.—S is the source of light, and $S\,P$ gives the candle-power in the direction $S\,P$. Mean candle-power in the plane of the paper equals the radius of the dotted circle.

In the examples shown in Figs. 2 and 3, S is the source, and the mean candle-power of S would be the same whether its candle-power curves were given by the curves or circles shown. The equation to the curve in Fig. 2 is—

$$r = a\,(1 + \sin\theta),$$

and to the curve in Fig. 3—

$$r = a\,(1 + \tfrac{1}{2}\sin\theta).$$

In the first case the area of the curve is 100 per cent. greater than the area of the circle, and in Fig. 3 it is 25 per cent. greater.

Graphical Construction.

When we have a polar diagram of the candle-power given, an obvious graphical construction to find the mean candle-power is to construct a new polar curve (see Fig. 6) so that—

$$r_1 = r^{\frac{1}{2}},$$

then—

$$\text{Mean C.P. in given plane} = \frac{\int_0^{2\pi} r\, d\theta}{2\pi}$$

$$= \frac{\frac{1}{2}\int_0^{2\pi} r_1^2\, d\theta}{\pi}$$

$$= \frac{\text{Area of new curve}}{\pi}.$$

If the candle-powers are given as in Figs. 4 and 5, then the mean horizontal candle-power is simply the mean height of the curve, *i.e.*, its area divided by its breadth.

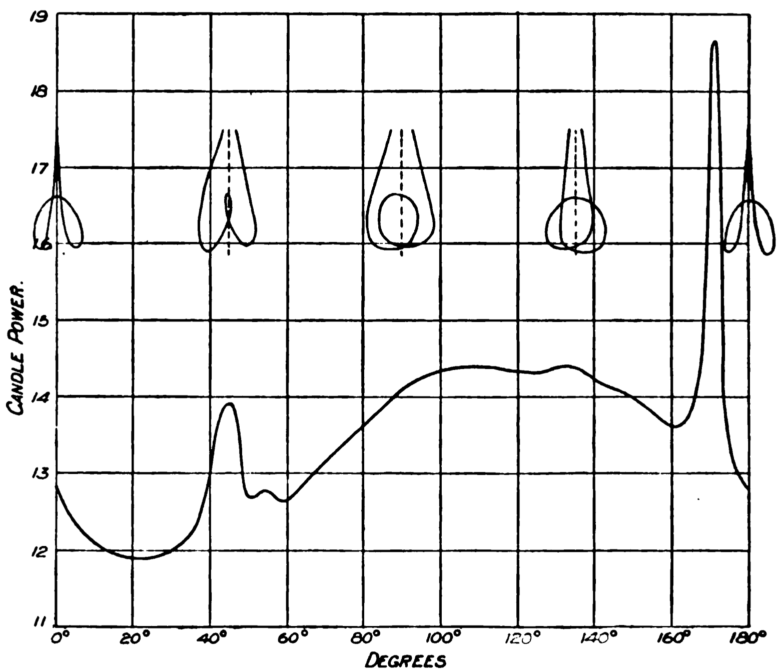


Fig. 4.—Mean horizontal candle-power curve round a clear bulb 16 candle-power glow lamp. Note the great rise of candle-power at 172 degrees due to the bulb acting like a concave mirror and concentrating the light on photometer disc. Distance of photometer head from lamp, about three feet.

Sufficient attention does not seem to be paid by practical men to the extraordinary way in which the horizontal candle-power of an ordinary glow lamp varies in different directions. In Figs. 4 and 5 are shown the results of the measurements of the candle-power of an ordinary glow lamp taken at intervals of every five degrees in the horizontal plane. The tests were made by two of my senior students,

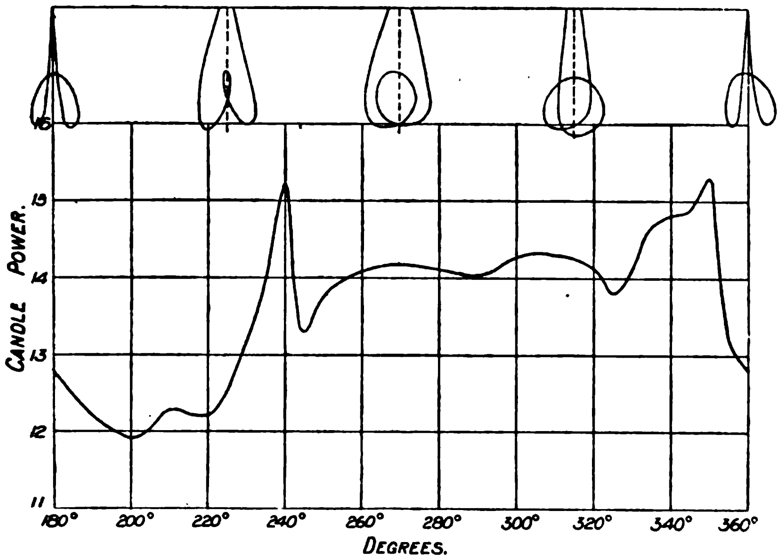


FIG 5.—Mean horizontal candle-power on the other side of the same lamp. Note the mirror effects at 240 degrees and at 350 degrees.

Messrs. Chubb and Morris, using a Lummer-Brodhun photometer, and they paid particular attention to the points where the candle-power altered rapidly. Their results may be taken as typical of how the horizontal candle-power of an ordinary glow lamp varies in different directions. The sudden variations are caused by the far side of the bulb acting like a concave mirror and concentrating the light on the photometer screen. In order to determine whether it acted like a lens or not a bulb was cut in two, but no trace of any lens effect could be found. The mirror effect was very pronounced, an image of a distant lamp being seen at a distance from the glass of about half the radius of curvature. On taking an ordinary lamp in your hand and looking into it with your back to a window two main images of the window will be seen, one erect and virtual formed by the front part of the bulb, the other inverted and real formed by the back part of the bulb. It is the back part of the bulb that causes the bright bands that can be seen on the shades of glow lamps. On putting your eye in line with a bright band coming from a glow lamp and moving it about, the image of the filament will be seen to behave in exactly the same manner as images do in concave mirrors. If a sheet of white paper be moved round it,

there will in general be positions in which bright bands of light are cast on the paper. Sometimes, especially in the case of ∩-shaped filaments, there will be dark bands. These dark bands are caused by one leg of the filament obscuring the light coming from the other leg. A ten per cent. dip from the mean is by no means unusual in this case.

When glow lamps are to be used as substandards of light it is necessary to test them first by finding their mean horizontal candle-power curve. If the candle-power is not sufficiently constant for a ten degree variation on either side of a given position, the lamp had better be rejected. Having found a suitable lamp and having marked distinctly and carefully the position in which it is to face the screen, it

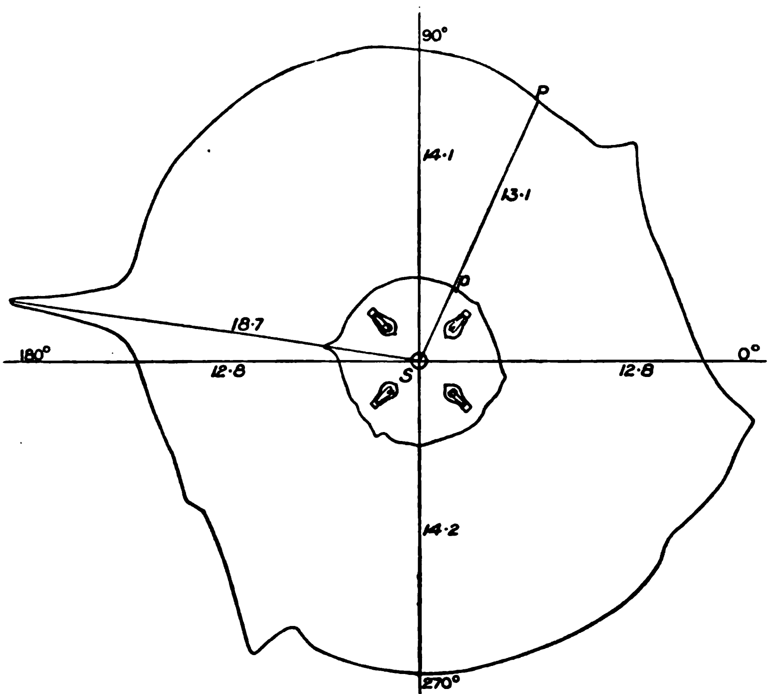


FIG. 6.—Polar horizontal candle-power curve of glow lamp. The radius vector $S\,P$ gives the candle-power in the direction $S\,P$. Also $S\,p = \sqrt{S\,P}$, and the area of the small curve divided by π gives the mean horizontal candle-power.

should then be run for a hundred hours, candle-power measurements being taken at frequent intervals to get an idea of the shape of the life curve. So far as constancy is concerned it is better to use low efficiency lamps as standards, and if care is taken that the pressure applied to them is never greater than the marked pressure and a record is kept of the time they are kept burning during tests, they will be found most satisfactory.

In Fig. 6, a polar curve of the candle-power of the glow lamp illustrated in Figs. 4 and 5 is shown. The mean horizontal candle-power was found by constructing a new curve, the lengths of whose radii are the square roots of the corresponding radii of the candle-power curve. The area of this curve divided by π gives 13·5 as the mean hemispherical candle-power of the lamp, a result which was verified by taking the mean height of the curves shown in Figs. 4 and 5.

As a rule, not much attention is paid to the mean vertical candle-power of ordinary glow lamps. The curve shown in Fig. 7 may be taken as typical.

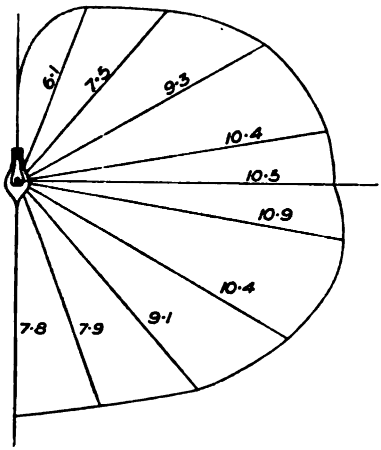


FIG. 7.—Vertical candle-power curve of ordinary glow lamp.

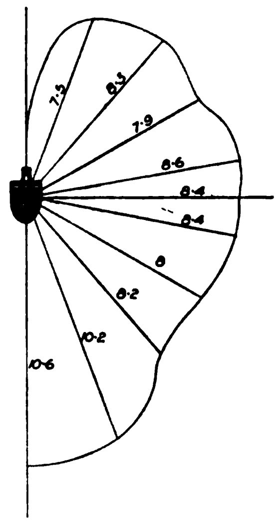


FIG. 8.—Vertical candle-power curve when a spiral glass rod twisted into the shape of a cup is placed round a glow lamp.

In Fig. 8 is shown the vertical candle-power curve of this lamp when a spiral rod twisted into the shape of a cup is placed round it. The shape of the candle-power curve is altered, but the change in the mean vertical candle-power is very slight.

RAPID METHODS OF GETTING THE MEAN HORIZONTAL CANDLE-POWER.

When the lamp is rotated, the centrifugal force alters the position of the filaments and generally alters the mean hemispherical candle-power. There is also a risk of the filaments breaking. Still, for rough measurements, the method is a good one.

Another method is to use four equal pieces of looking-glass cut from the same strip. Two of these pieces inclined to one another at 120

degrees are placed behind the standard lamp, and an exactly similar arrangement is placed behind the lamp being tested. If then the candle-power of the lamp being tested is approximately the same as that of the standard and the mean horizontal candle-power of the standard is accurately known, we get by one reading an approximation to the mean of three, and so time is saved. Great accuracy, however, is not obtainable by this method if only one reading is taken, as variations of five per cent. can be obtained by rotating the lamp into different positions, these variations being mainly caused by the positions of the bright bands.

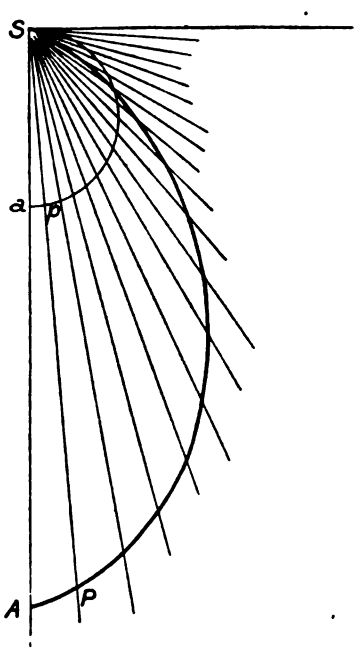


FIG. 9.—The revolution of SPA about SA produces the candle-power surface. Make a new curve Spa so that $Sp = \sqrt[3]{SP}$. Then the mean spherical candle-power $= \frac{3V}{4\pi}$, where V is the volume generated by the revolution of Spa round Sa. Mean spherical candle-power $= 0{\cdot}125\, SA$.

Experiments were made with diffusive reflectors, but in no case could we make sure of obtaining a five per cent. accuracy by one reading. Better results would probably be obtained by using uniform ground-glass cylindrical chimneys to put round the lamps when being tested.

MEAN SPHERICAL CANDLE-POWER.

If we draw from the source, equally in all directions, lines whose lengths are proportional to the candle-power in these directions, then the mean value of the lengths of all these lines is the mean spherical candle-power. If $r_1, r_2 \ldots r_n$ be the intensity of the light in the various directions, then—

$$\text{M.S.C.P.} = \frac{r_1 + r_2 + \ldots + r_n}{n}$$

$$= \frac{\Sigma r\, d\omega}{4\pi},$$

where $d\omega$ stands for a very small solid angle.

Hence, if we construct a new surface so that—

$$r_1 = r^{\frac{1}{3}},$$

then—

$$\text{M.S.C.P.} = \frac{\Sigma\, r_1^3\, d\omega}{4\,\pi}$$
$$= \frac{3\,\Sigma\, d\,\text{V}}{4\,\pi}$$
$$= \frac{3\,\text{V}}{4\,\pi},$$

where V is the volume of this new surface.

It will be seen that an exact solution of the general problem is complicated. When, however, as is generally permissible in practice, we may suppose that the extremities of all the lines representing the candle-powers lie on a surface of revolution, various simple graphical methods may be given to find the main spherical candle-power.

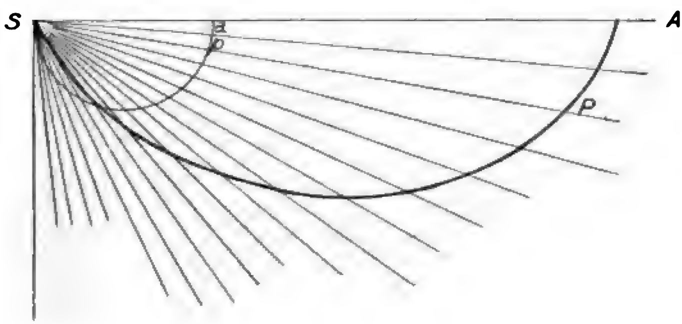


FIG. 10.—*S P A* is the polar curve of candle-powers in directions below the horizontal in a vertical plane. If the top polar curve be similar, then the mean spherical candle-power = 0·589 *S A*.

FIRST GRAPHICAL METHOD.

We first find by experiment the polar curve S P A (Fig. 9), whose revolution produces the candle-power surface. We then construct a new curve S *p a* so that—

$$\text{S}p = \text{SP}^{\frac{1}{3}}\,.$$

It follows that the—

$$\text{M.S.C.P.} = \frac{\text{S P}\, d\omega + \ldots}{4\,\pi}$$
$$= \frac{\text{S}p^3\, d\omega + \ldots}{4\,\pi}$$
$$= \frac{3\,\text{V}}{4\,\pi}$$
$$= \frac{3}{4\,\pi} \times 2\,\pi\, h \times \text{Area S}\,p\,a,$$

where *h* is the perpendicular distance of the centre of gravity of the area S *p a* from S A.

For example, in Fig. 9 the curve $S p a$ is a circle. Hence in this case the—

$$\text{M.S.C.P.} = \frac{3}{4\pi} \times 2\pi \left(\frac{2\,S a}{3\pi}\right) \times \frac{\pi}{2} \left(\frac{S a}{2}\right)^2$$
$$= \frac{1}{8} \left(S a\right)^3$$
$$= \frac{1}{8} \,.\, S A.$$

Similarly in Fig. 10, where $S p a$ is a circle (only half the curve is drawn)—

$$\text{M.S.C.P.} = \frac{3}{4\pi} \times 2\pi R \times \pi R^2$$
$$= \frac{3\pi}{2} R^3$$
$$= \frac{3\pi}{16} S A$$
$$= 0{\cdot}5890\ S A.$$

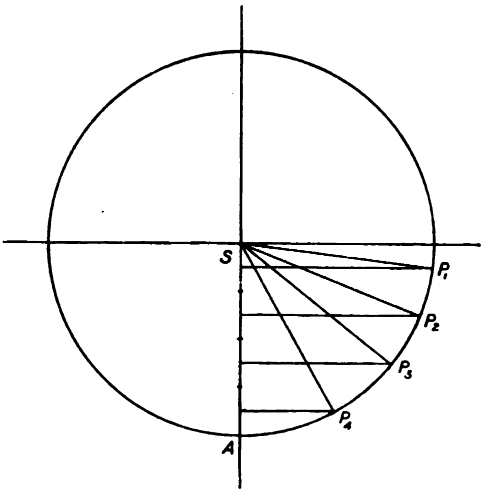


FIG. 11.—Construction for finding the directions in which to measure the candle-powers whose mean value will give us the mean spherical candle-power. *S A*, the lower radius of a circle, is divided into any number of equal parts, and through the middle points of these equal parts lines are drawn perpendicular to *S A*. $S P_1$, $S P_2$, etc., are the required directions.

ANOTHER EXPRESSION FOR THE M.S.C.P.

With the source S as centre, describe a sphere (Fig. 11) of radius R. Divide the vertical diameter of this sphere into any number of equal parts, and through the points of section draw planes perpendicular to

this diameter, then these planes will intersect zones of equal area on this sphere. This follows from elementary mensuration, since the area of the zone of a sphere is $2\pi R h$, where h is the perpendicular distance between its two bounding planes. Now, if we take the mean value of the candle-powers in the directions of all the radii drawn to one of these zones and do the same for all the others, the mean of all these results will give us the mean spherical candle-power.

For the case of a surface of revolution, if $R = n h$—

$$\text{M.S.C.P.} = \frac{r_1 + r_2 + \ldots + r_{2n}}{2n}$$

$$= \frac{r_1 h + r_2 h + \ldots}{2R}$$

$$= \frac{\Sigma r h}{2R}.$$

Now $h = R\,d\theta \cos\theta$,

$$\therefore \quad \text{M.S.C.P.} = \tfrac{1}{2}\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} r \cos\theta\, d\theta$$

$$= \tfrac{1}{2}\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} x\, d\theta,$$

which is a simple formula.

For example, if the polar curve of candle-power be the semicircle of $S p a$ in Fig 9, and a similar semicircle above the horizontal, then

$$\text{the M.S.C.P.} = 0{\cdot}5 \,.\, S a.$$

Similarly, if it were the circle half of which is shown in Fig. 10,

$$\text{the M.S.C.P.} = \tfrac{1}{2}\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} 2R \,.\, \cos^2\theta\, d\theta$$

$$= \frac{\pi}{2} R$$

$$= 0{\cdot}7854 \,.\, S a.$$

The equations to the curves shown in Figs. 2 and 3 are of the form—

$$r = a + b \sin\theta.$$

Hence the M.S.C.P. of the surfaces of revolution of which they are sections—

$$= \tfrac{1}{2}\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} (a + b \sin\theta) \cos\theta\, d\theta$$

$$= a$$

The curves shown in Fig. 12 are parts of circles; in this case—

$$\text{M.S.C.P.} = 0{\cdot}555 \ . \ \text{O A}.$$

In Fig. 2 the ratio of the two hemispherical candle-powers is as one is to three.

Mean Hemispherical C.P.

In this case we only take the mean value of the candle-power over a hemisphere. The formula is—

$$\text{H.C.P.} = \int_{0}^{+\frac{\pi}{2}} x \, d\theta,$$

For example, in Figs. 2 and 3—

$$\text{Upper H.C.P.} = a - \tfrac{1}{3} b.$$
$$\text{Lower H.C.P.} = a + \tfrac{1}{3} b.$$

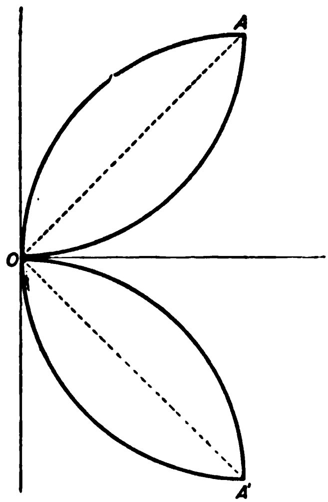


Fig. 12.—The revolution of the polar curves shown, which are parts of circles, gives us the candle-power surface. Mean spherical candle-power = 0·555 OA.

Second Graphical Method.

Having given the polar curve of candle-power A P B C (Fig. 13) construct a new curve so that—

$$o p = \sqrt{o \text{N}},$$

then the area of this new curve gives the M.S.C.P. For—

$$\text{Area of Curve} = \tfrac{1}{2}\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} o\,p^2\,d\theta$$

$$= \tfrac{1}{2}\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} x\,d\theta\,. = \text{M.S.C.P.}$$

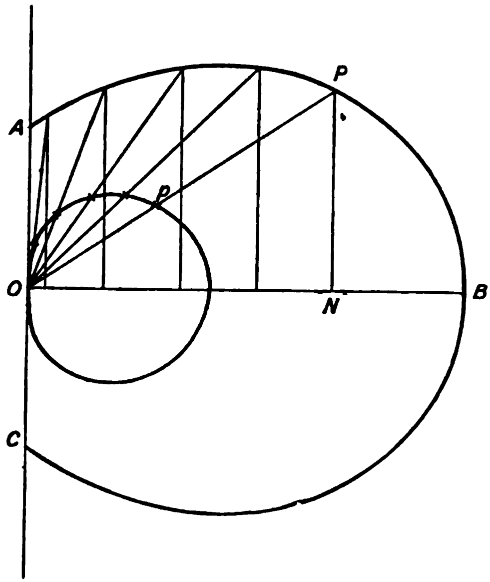


FIG. 13.—O is the source of light and $A\ P\ B\ C$ is the polar curve of candle-power. Make $O\,p = \sqrt{O\,N}$ and construct the curve locus of p. The mean spherical candle-power = the area of the small curve.

RAPID METHODS OF FINDING M.S.C.P.'S.

The following approximate methods will be found of practical value. The theory will be best understood by considering a particular case. Divide a sphere described round the source as centre into eight equal zones (Fig. 11). Through the centres of the equal parts into which the radius is divided draw perpendiculars meeting the surface in P_1, P_2, P_3, and P_4 respectively, and suppose that corresponding lines are drawn for the upper hemisphere. Then we may assume that the candle-powers in the directions $S\,P_1$, $S\,P_2$, etc., are all equally important.

Hence $$\text{M.S.C.P.} = \frac{r_1 + r_2 + \ldots + r_8}{8}.$$

where r_1, r_2 . . . are the intensities of the light in the directions SP_1, SP_2. . . . The lower hemispherical candle-power would be given by the approximate formula—

$$\text{Lower H.C.P.} = \frac{r_1 + r_2 + r_3 + r_4}{4}.$$

If we find the angles of depression, SP_1, SP_2 . . . once for all, then we can take these as standard directions. The mean spherical candle-power can be got directly by this method without any graphical construction.

If the lower radius be divided into 2 n portions, then the angles are given by the equations—

$$\text{Cos } \theta_1 = 1 - \frac{1}{2n}.$$

$$\text{Cos } \theta_2 = 1 - \frac{3}{2n}.$$

$$\text{Cos } \theta_n = 1 - \frac{2n - 1}{2n} = \frac{1}{2n}.$$

If radii be drawn making angles $\pm \theta_m$ with the horizontal, and if I_m and I'_m be the intensities of the light in these directions, then—

$$\text{M.S.C.P.} = \frac{I_1 + I_2 + \ldots + I_1' + I_2' + \ldots}{2n}.$$

$$\text{Upper H.C.P.} = \frac{I_1 + I_2 + \ldots}{n}.$$

$$\text{Lower H.C.P.} = \frac{I_1' + I_2' + \ldots}{n}.$$

The following are the values of θ_1, θ_2, etc., when 2, 4, 6, 8, 10, or 20 measurements of candle-power are to be made :—

Number of Measurements.	Angles of Depression or Elevation from Horizontal in Degrees.
2	30
4	14·5, 48·6
6	9·6, 30, 56·4
8	7·2, 22, 38·7, 61
10	5·7, 17·5, 30, 44·4, 64·2
20	2·9, 8·6, 14·5, 20·5, 26·7, 33·4, 40·5, 48·6, 58·2, 71·8

Approximations to the mean spherical candle-power of any required accuracy can thus be obtained by measuring the candle-powers in the directions of the angles given above and taking the arithmetical mean of the results.

In order to illustrate the accuracy of these approximations the following numerical examples have been worked out :—

In Fig. 10 the lower hemispherical candle-power of the polar curve S A P comes out as follows :—

Number of Measurements.	Lower H.C.P.
1	0·6495
2	0·5979
3	0·5924
4	0·5904
5	0·5901
10	0·5893
Infinite	0·5890

The first approximation is simply got by measuring the candle-power at 30 degrees, the next by taking the mean of the values at 14·5 and at 48·6 degrees respectively, and so on.

In this case the mean of the candle-powers in directions 9·6, 30 and 56·4 would have been sufficiently accurate.

The following are the approximations to the lower hemispherical candle-power of the polar curve S P A in Fig. 9.

Number of Measurements.	Lower H.C.P.
1	0·1250
2	0·2188
3	0·2359
4	0·2422
5	0·2450
10	0·2500
Infinite	0·2500

Many other examples have been worked out, and it has been found that the mean of five observations at angles of 5·7, 17·5, 30, 44·4, and 64·2 are quite sufficient for practical requirements.

Even, however, when theoretically accurate methods like Rousseau's or the graphical methods we have described are employed, it is always best to measure the candle-powers in the directions given above for the tenth approximation and not at ten equal angular intervals, because in this latter case undue importance is attached to measurements at 60, 70 and 80 degrees. As a rule, an error in the measurement when the angle of depression is ten degrees is much more serious than when the angle of depression is eighty degrees.

The points to which attention is called in this paper are the following :—

1. The bulbs of glow lamps act like concave mirrors producing bands of light in particular directions. Dark bands are produced when a vertical portion of the filament is parallel to another portion of it. These effects produce very rapid azimuthal variations of the light.

2. In determining the mean hemispherical candle-power of glow lamps, when no reflectors or diffusers are used, a large number of observations must be made. This number may be reduced by using suitable reflectors or diffusers. If we rotate the lamp, besides the risk of the filament breaking, the centrifugal force must alter its shape, thus altering the total distribution of the light in space.

3. When glow lamps are used as standards it is of vital importance to study the horizontal candle-power curve before choosing and marking the direction in which they are to face the photometer screen. Neglect of this precaution even with ∩-filament lamps leads to large errors. As a rule the plane of the filament is perpendicular to the axis of the bench. The mean horizontal candle-power curves got by comparing a lamp with two standards of different powers may show distinct variations due to the relative mirror effects of the bulb being different at varying distances of the photometer screen from the lamp.

4. Several simple formulæ and graphical constructions are given for determining the mean spherical and the mean hemispherical candle-power of sources of light.

5. The simplest practical method of determining the mean lower hemispherical candle-power of an arc lamp is to measure its candle-power in directions making angles of 5·7, 17·5, 30, 44·4, and 64·2 degrees with the horizontal, and taking the mean of the results. The easiest way of drawing these angles is by the graphical construction indicated in Fig. 11. If greater accuracy is required, the same thing can be done in several vertical planes passing through the axis of the lamp and the mean of the results taken.

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GLASGOW LOCAL SECTION.

A STUDY OF THE PHENOMENON OF RESONANCE IN ELECTRIC CIRCUITS BY THE AID OF OSCILLOGRAMS.*

By M. B. FIELD, Member.

(*Paper read at Meeting of Section, February 10th*, 1903.)

Three factors are generally essential to enable an intelligent investigator to satisfactorily complete any experimental research, viz., time, inclination, and apparatus.

During the last two years I have been in the enviable position of having at my disposal plant and apparatus, from which by careful study many important and, I believe, little understood phenomena might be investigated. The inclination on my part to make the best use of the opportunity afforded certainly was not wanting; but the small quantum of available spare time has hindered me from bringing to a satisfactory termination several investigations on which I have been at work.

As in future I shall not have in the same way facilities for continuing this work, I venture to lay before you in all their incompleteness certain results I have arrived at, and to ask you to consider these as mere suggestions, which may act as an incentive to some other fortunate investigator, who may have the time, apparatus, and inclination necessary for completing the work.

My subject is more particularly some aspects of electrical resonance which occurred to me on observing the shape of the E.M.F. wave of the 2,500 kw. generators of the Glasgow Corporation Tramways Department. These curves were depicted on the tracing desk of one of those beautiful instruments invented by Mr. Duddell, viz., the high frequency pattern of oscillograph.

* This Paper was also read in abstract in London on March 12th, 1903, and was discussed jointly with Messrs. Constable and Fawsett's Paper, "Distribution Losses in Electric Supply Systems," at Meetings of March 12th, 26th and April 23rd, 1903. See pages 734, 740, and 762.

At first I contented myself with merely tracing on paper the curves thrown upon the desk of the apparatus. When, however, I wished to obtain curves which were to play an important part in some of the official tests of the Glasgow plant, I considered this method too inaccurate, and had constructed several special dark slides in which a bromide paper or sensitive film could be stretched round a glass shaped to the proper curvature, and by means of which records could be taken photographically and the human element obviated. These dark slides were cheap to construct, and very useful, and were used almost entirely in the experiments I am about to describe.

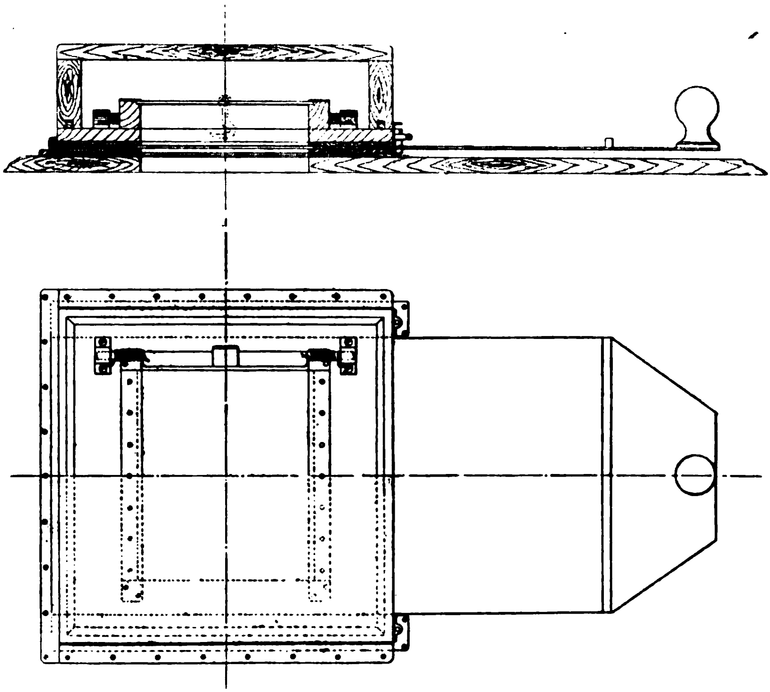


FIG. 1.

Fig. 1 is a drawing of the dark slide, which is self-explanatory. In using these, of course, all stray light must be screened off to obtain the best results; and in this connection I found it useful to employ a screen (S, Fig. 2) to cut off all light from the bright lacquered parts of the oscillograph. Many of these parts are best painted with a dead black paint, while it is of the highest importance to entirely cover the bright steel face containing the saw-cuts in which the vibrating strips are set. I found it advantageous to make several slight modifications of this kind in the apparatus as supplied by the makers in order to obtain the best results with the dark slides above mentioned.

It may be of interest to call attention here to a few of the idiosyncrasies of the type of oscillograph employed.

In the first place, I experienced considerable difficulty due to the shifting of the zero of the vibrating mirror. The apparatus contains a fixed mirror which gives a fixed zero line, and it is necessary to adjust each of the vibrating mirrors so that the base line (they project when no current is flowing through them) coincides with the fixed zero line. After the strips have been in circuit for a short while, however, I found frequently that the zero line had shifted, which produced the apparent result of larger positive half-waves than negative half-waves, or *vice versa*. Again, there is a tendency for the cam which vibrates the mirror to wear, and the greatest wear occurs towards the end of the motion, since here the pressure on the cam is greatest. This wear affects the horizontal, but not the vertical, displacement, the latter still being directly proportional to the current flowing. In some cases, therefore, where the positive and negative half-waves were obviously

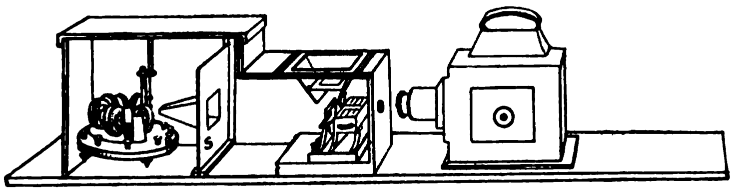


FIG. 2.

identical, I found it advantageous to apply a correction in the following way:—Two lines were drawn parallel to the fixed zero line touching the highest point of the positive and negative waves; the distance between these lines was halved and a corrected zero line drawn in; the positive half-wave was then reversed and substituted for the negative half, thus almost entirely eliminating the above-mentioned effects. This, of course, would not be permissible where the positive and negative half-waves were of different shape. I may say that all the curves here reproduced have been *uncorrected* in this manner.

Another difficulty I experienced was due to the violent hunting of the oscillograph motor when running under abnormal conditions. Under these circumstances two distinct waves would be apparent on the photograph, representing the limiting positions of the actual wave which the projection of on the screen was shifting backwards and forwards with great rapidity, instead of being stationary, as it should have been.

Sometimes this hunting was caused by the variation of load on the oscillograph motor (the tension of the spring controlling the mirror varying from zero to a maximum in each revolution).

Curve I. represents the E.M.F. curve of the system under normal load conditions, with one 2,500 kw. generator only running on the load, and supplying 245 amperes per phase. The generators are 6,500 volt, 3-phase, 75 r.p.m. machines, with stationary armatures having two

slots per pole per phase, and 40 poles. Curve I, as also practically all oscillograms reproduced in this paper, was taken from the low-tension side of a bank of transformers in one of the sub-stations; there were thus a bank of transformers and a high-tension 3-core cable intervening between the oscillograph and the generator terminals.

I fully recognise that it would have been more to the point had some of my measurements been made in the high-tension circuit itself. I even constructed a resistance to insert in one of the legs of the

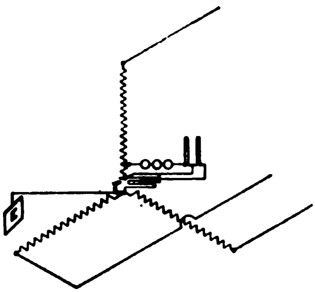
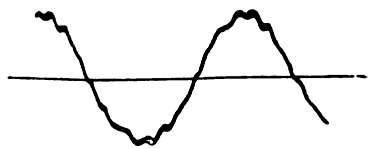


FIG. 3.



CURVE I.—E.M.F. Wave of Generator on normal traction load, 245 amps. per phase.

armature winding, and took a tapping off one of the coils near the neutral point, as shown in Fig. 3. It was my intention to connect the neutral point of the generator to earth during these experiments in order to secure safety, it being normally insulated from earth. I had not, however, the same facilities in the power-house as in the sub-station, and unfortunately did not conduct any experiments in the former place.

The arrangement generally adopted was that shown in Fig. 4—

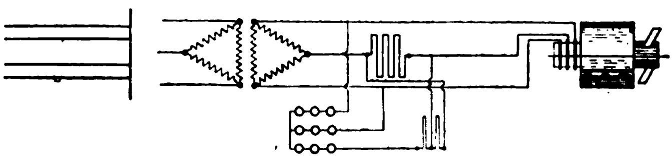


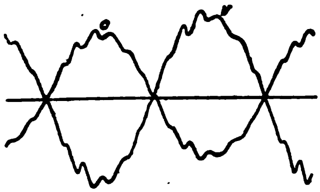
FIG. 4.

The transformer groups consist each of three 200 kw. single-phase transformers connected △ — system, and loaded on rotary converters. The high-tension cables are as follows:—

To Sub-station	A	4 — 3-core	·15 in.	Length = 4849 yards	each.
„	B	4 — 3-core	·1 in.	„ = 4,775	„
„	C	4 — 3-core	·1 in.	„ = 5,899	„
„	D	4 — 3-core	·1 in.	„ = 2,286	„
„	E	4 — 3-core	·15 in.	„ = 5,605	„

An examination of Curve I. will show at a glance that there are harmonics of a high order present in the wave form. Curve II.

represents the voltage and current wave forms taken from the low-tension side of one of the 200 kw. transformers partially loaded on a water resistance. It will be noticed that for clearness the current wave has been reversed, that there is apparently no phase displacement, and that the harmonics of the current wave follow closely those of the E.M.F.



CURVE II.—E.M.F. and Current Waves from Transformer on water load.

Assuming we can represent the E.M.F. wave by the expression

$$E = \Sigma E_i \sin(2\pi i n t + e_i) \quad . \quad . \quad (1)$$

n being the natural frequency of the system, *i.e.*, 25 cycles per second, and the summation being extended to all terms obtained by giving i successive integral values from 1 upwards, then the true voltmeter reading of E, or the effective volts, will be—

$$\sqrt{\frac{\Sigma E_i^2}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and provided the water load acts as a true non-inductive resistance, and one without capacity, *i.e.* provided no periodic storage and discharge of energy occurs in the water resistance, the current will be expressed by—

$$\frac{1}{R} \Sigma E_i \sin(2\pi i n t + e_i) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and the true ammeter reading by $\frac{1}{R}\sqrt{\frac{\Sigma E_i^2}{2}}$ . . . . (4)

The products of the ammeter and voltmeter readings will then be—

$$\frac{1}{2R} \Sigma (E_i^2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

The instantaneous value of the watts, obtained by multiplying the instantaneous values of voltage and current strength, is—

$$\frac{1}{R}\left\{\Sigma E_i \sin(2\pi i n t + e_i)\right\}^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

the average value of this, or the true wattmeter reading, is, of course, again represented by the expression (5); in other words, if the load be a pure ohmic resistance, the product of true volts and true amperes represents true watts, no matter how irregular the wave-shapes may be.

Now the value of (2) may be obtained from the oscillogram of the voltage, by taking the square root of the average value of the squares of a number of equi-distant ordinates.

Similarly the value of (4) may be determined from the current oscillogram.

Multiplying these together we obtain the value of (5).

The average value of (6) may be determined by first multiplying the ordinates taken from the current and voltage oscillograms, and then taking the mean.

To test the water load, as also the oscillograph, I obtained arithmetically the values of (2), (4), (5), and the average value of (6), as described from the oscillograms, and in every case obtained agreement within 1 per cent.

It is clear that, had the load possessed any properties of the nature of self-induction or capacity, or if such factors existed in the oscillograph itself, such agreement would not have been obtained.

It was natural to inquire what effect the harmonic or ripple in the E.M.F. wave would have on the voltage at the rotary D.C. brushes. To show this, I drove the oscillograph motor from the rotary slip-rings, connecting one strip across the D.C. brushes, and one strip between one slip-ring and one D.C. brush (see Fig. 5).

The result was Curve III. A distinct ripple was observable in the D.C. voltage under normal load conditions, and by comparing it with the wave length of the undulating wave we find the number of ripples

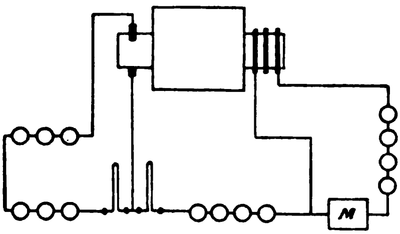
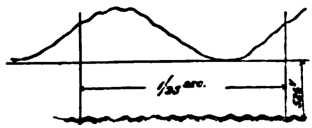


FIG. 5.



CURVE III.—D.C. Voltage of Rotary on no Load and E.M.F. between one D.C. brush and slip-ring.

in the D.C. voltage per period is 12; in other words, there is an alternating E.M.F. of 300 cycles superimposed upon the D.C. voltage of 500 volts.

It is clear that the E.M.F. between one slip-ring and one commutator brush will be an undulating E.M.F. either wholly positive or wholly negative. If the negative D.C. brush is at zero potential, and provided the rotary is on load, and the brushes are in the neutral position, clearly every other point in the armature, if not at zero potential, must be between zero and the potential of the + D.C. brush. Now, each slip-ring becomes connected directly to the + and — brush alternately once per cycle, hence shape of wave.

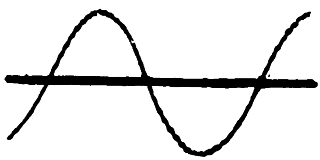
Until I saw this experiment I had half doubts that the ripples in the A.C. voltage were introduced by the oscillograph itself. When, however, I ran a rotary as a double current generator, self-excited, driving it by means of its starting motor, the D.C. voltage shown by the oscillograph was a perfectly straight horizontal line, and the A.C. wave was entirely devoid of ripples except of a very much higher frequency and small amplitude.* (See Curve IV.)

* From Curve IV. it appears as though there were 35 or 37 ripples per period. It may be pointed out that the armatures of these rotaries are six-polar, and have 108 slots, this apparently corresponding to the number of ripples in the oscillogram.

The process of parallelling could be watched on the oscillograph screen, and a most fascinating sight it is to watch the D.C. voltage spring from the straight line to a wave with ripples along the whole length, and then to see the main wave instantaneously straighten out, the ripples only remaining as the rotary is pulled into the correct phase. The instantaneous formation of the ripples on the A.C. curve can in like manner be watched.

It was easy, however, to demonstrate the existence of the D.C. ripples independently of the oscillograph, and for this purpose I dróve one rotary by an independent motor as a D.C. generator, and a second rotary parallel with the power-station in the usual way. The two + brushes were connected together, and the negative brushes through a hot-wire voltmeter in parallel with a Weston. The excitation was adjusted till the latter voltmeter read zero; the hot-wire instrument on the other hand indicated 12 volts. The latter instrument was, of course, merely measuring the square root of the mean square of the ripple.

This corresponds to a total fluctuation from crest to hollow of 34 volts, or, say, *under normal running conditions*, 6·8. I have tried to filter out the alternating component of the D.C. voltage, and transform it up, by passing it round one winding of a static transformer, neutralising the magnetic saturation created by the D.C. component by a current from a battery, but I have not succeeded in doing it.



CURVE IV.—E.M.F. Curve of Rotary as A.C. Generator.

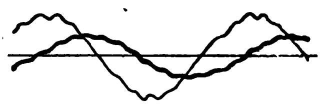
If I could have borrowed a 500-volt accumulator battery in order to oppose it to the D.C. voltage of the rotary, I think I could have obtained a considerable 300-cycle current through the battery. As I shall show afterwards, I am able to accentuate these D.C. ripples considerably under special circumstances.

I further observed the current flowing into the D.C. feeder circuits of the tramway system, but could find practically no trace of a ripple at all. The loss in outside circuits due to the ripple was therefore negligible.

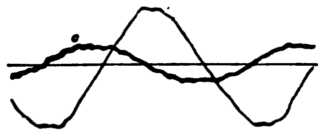
If we took the square root of mean square of the voltage ripple as 3 per cent. of 500 volts, and the current ripple in proportion, viz., 3 per cent., and if we assumed that the whole of the A.C. component was wasted in heat, it would represent merely 9 units in 10,000. I am therefore justified in saying that under normal conditions the loss due to the D.C. ripple does not amount to 1 per mil.

There is no doubt that the source of these ripples lies in the teeth of the generators, there being 12 teeth per period and 12 ripples per cycle superimposed on the D.C. voltage. The ripples exist in the high-tension voltage, pass through the transformers, through the rotaries to the D.C. side, and if other rotaries be run as motors from the D.C. 'bus-bar, the ripples reappear at the A.C. slip-rings. It seems impossible to get rid of them by filtering them out. We have already

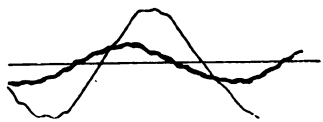
disposed of the suggestion that they originate in the rotaries themselves. I think no one will venture to assert that the transformers manufacture them. One way to decide that point would be to connect the oscillograph direct in the high-tension circuit; although I have not done this, I have another proof (although to my mind no proof is necessary), and that is, when one generator only is running in the power-house the ripples are always present, though somewhat wavering at times—when two generators are running in parallel the ripples often alternately appear and disappear with a regular periodicity lasting several seconds. This is evidently due to the swinging of one



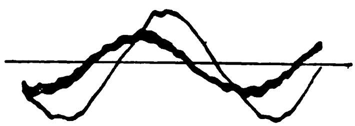
CURVE V.—Current and E.M.F. of Rotary on no load, under-excited. Lagging current into rotary = 650 amps.



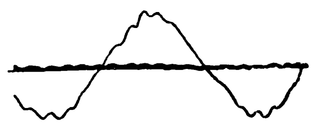
CURVE VI.—Same as V., but over-excited. Leading current into rotary = 600 amps.



CURVE VII.—Current and E.M.F. of Rotary on normal traction load, in parallel with two others.



CURVE VIII.—Current and E.M.F. of Rotary on normal traction load, in parallel with one other.



CURVE IX.—E.M.F. and Current of Rotary on no load, excitation adjusted to give minimum armature current.

generator relatively to the other; when exactly in phase the ripples appear, when displaced by half the wave length of the ripple they practically disappear. The same thing happens with the ripples in the A.C. voltage. I have seen an almost rounded A.C. voltage curve suddenly jump into peaks as one generator was switched out of parallel.

Granting, then, that the generator E.M.F. wave possesses high harmonics, and the back E.M.F. of the rotaries is a smooth wave (as indeed one would expect from such a type of armature, and as is shown to be the case in Curve IV.), it is evident that the rotary can supply no back E.M.F. to equilibriate the ripples of the applied E.M.F. What must happen in such a case is that when the opposing E.M.F.'s do not balance owing to a ripple in the one and not in the other, a

wattless—which I afterwards call a self-induction—current must rush in or out of the rotary, which will absorb or equilibriate the difference of voltage. Curves V. to IX. show this clearly. In the latter case the rotary was running unloaded under condition of minimum armature current. It will be seen that the amplitude of the ripples of the current waves seems larger than that of the main wave itself, the latter being scarcely distinguishable.

It is interesting to note that the current wave is rippled more uniformly than the voltage wave.

The main drift of the first portion of this paper is to discuss the conditions under which resonance may occur with one of the higher harmonics of the E.M.F. wave introduced by the particular form of toothed armature in use at the power-station. Let us first examine the construction of the armature. Fig. 6 is reproduced from a scale drawing of the armature slots, and field magnet pole-shoes. From an examination of this figure it will be obvious that the magnetic flux must

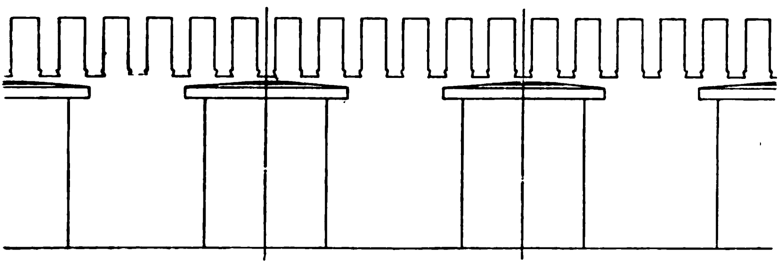


FIG. 6.

be constantly shifting backwards and forwards along the pole-face as tooth by tooth of the armature is passed. It does not necessarily mean that the total flux through the field system fluctuates, but that this flux emerges from the pole-face in "tufts" opposite the armature teeth, and that these tufts of magnetism are dragged backwards, and spring forwards along the pole-face according as the magnetic reluctance is charged at different parts of the same by the change of position relative to the armature teeth. The poles are champfered off so as to avoid as far as possible change of total flux through the field system. I do not think this goes on to any marked extent; it would be possible to detect such periodic changes by looking for fluctuations of exciting current. This could be done by suitably inserting the oscillograph in the exciter circuit.* On the other hand, an examination of Fig. 6 would lead us to expect six more or less sudden irregularities or excrescences per half-wave of the curve representing total threading of magnetic flux † by the armature coils. This does not mean a 12th

* I have tried this experiment under difficulties, and certainly detected slight and rapid periodic fluctuations in the exciting current. The experiment is well worth repeating, however, my results being by no means conclusive.

† By threading of magnetic flux I wish to indicate the sum total of magnetic flux interlinked with each turn of the armature winding.

harmonic; an even harmonic would be impossible with such a generator—it would mean that the positive half-wave was of a different shape from the negative half, and the right-hand half of each half-wave was of a different shape from the left-hand half. This, of course, with such a generator is impossible.*

If, however, we consider a smooth wave (not necessarily a sine wave) with 6 ripples per half-period superimposed in the manner indicated in Fig. 6A so that the ripples are wholly positive during the positive half-period and wholly negative during the negative half-period, we

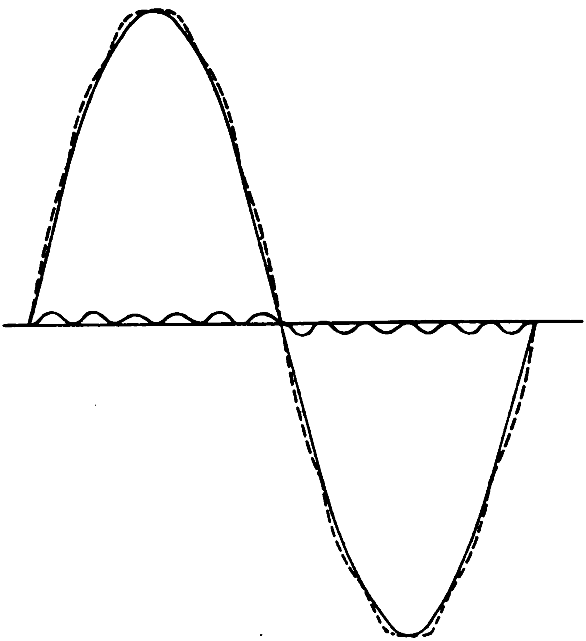


FIG. 6A.

should get a curve such as we might reasonably expect with a 12 slot per period alternator. This curve of total threading of magnetic flux would be quite symmetrical, and would possess 12 irregularities corresponding to the number of teeth.

It is therefore instructive to study this case, and to simplify matters we will assume that the ripple between o and π can be represented as

* In making this statement I am leaving out of account all extraneous effects, such as hysteresis in the armature teeth, cross magnetisation, etc. Later on we find curves in which the right and left halves are different owing to some such effects, in all probability. I mean here that, provided the winding, slots, pole-pieces, etc., are symmetrical, the process of the flux cutting into an armature coil must be the exact reverse of cutting out of a coil; moreover, the flux from an S-pole must of necessity cut in and out in the exact manner as does the flux from the N-pole.

$a\,(1 - \cos 12\,kt)$ and between π and $2\,\pi$ as $-a\,(1 - \cos 12\,kt)$. The fundamental term is F N sin kt (F N being the maximum interlinkage of flux with armature winding).

Now, we can quite easily split this up into a Fourier's series; the amplitude of the p^{th} sine term will be proportional to *—

$$f_1(\pi) - f_1(o),$$

and of the p^{th} cosine term to—

$$f_2(\pi) - f_2(o).$$

Where $f_1(k\,t)$ represents—

$$\int (1 - \cos 12\,kt) \sin pkt\;dt \text{ or } -\frac{1}{pk}\cos pkt + \frac{\cos(p+12)\,kt}{2\,(p+12)\,k} + \frac{\cos(p-12)\,kt}{2\,(p-12)\,k}.$$

and $f_2(k\,t)$ represents—

$$\int (1 - \cos 12\,kt) \cos pkt\;dt \text{ or } \frac{1}{pk}\sin pkt - \frac{\sin(p+12)\,kt}{2\;p-12)\,k} + \frac{\sin(p-12)\,kt}{2\,(p-12)\,k}.$$

If p is even, $\cos(p \pm 12)\,\pi = +1$.
If p is odd, $\cos(p \pm 12)\,\pi = -1$.
If p is odd or even, $\sin(p \pm 12)\,\pi = 0$.

$\therefore\; f_1(\pi) - f_1(o) \propto \left(\frac{1}{p} - \frac{p}{p^2 - 144}\right)$ where p is odd,
$f_1(\pi) - f_1(o) = o$ " even,
$f_2(\pi) - f_2(o) = o$ " odd or even.

This shows us that in this expansion the odd harmonics only enter in, and they are all *sine* terms.

Now, $p/(p^2 - 144)$ becomes infinite when $p = 12$, as p can only have odd integral values we see that the 11th and 13th harmonics are the most important.

The relative amplitudes of the harmonics in the expression for E.M.F. are obtained from those representing total interlinkage of flux by multiplying by the corresponding order of harmonic. This has been represented in the following table:—

	Flux.		E.M.F.
7th Harmonic,	$\frac{1}{7} + \frac{7}{95} =$	·215	1·50
9th "	$\frac{1}{9} + \frac{9}{63} =$	·253	2·27
11th "	$\frac{1}{11} + \frac{11}{23} =$	·568	6·24
13th "	$\frac{1}{13} - \frac{13}{25} =$	− ·444	− 5·77
15th "	$\frac{1}{15} - \frac{15}{81} =$	− ·119	− 1·78
17th "	$\frac{1}{17} - \frac{17}{145} =$	− ·059	− 1·00

* The full expression is, of course—
$\left\{f_1(\pi) - f_1(o)\right\} + \left\{-f_1(2\,\pi) + f_1(\pi)\right\}$ which in our case is $2\,[f_1(\pi) - f_1(o)]$.

We may say generally that the most important harmonics where there are q teeth in the generator per pair of poles are the

$$(q - 1)^{th} \text{ and the } (q + 1)^{th},$$

unless indeed the grouping of the armature conductors is such as would naturally introduce other harmonics of important magnitude, independent of whether the armature be smooth or not.

The question now arises whether 12 ripples in the D.C. voltage per cycle are consistent with an 11th and 13th harmonic. I think so. If we consider the 13th harmonic occurring similarly in the three phases, A, B, C, then the harmonic in phase B will be 120 deg. of its own period in advance of the harmonic in A. Similarly the harmonic in C will be in advance of that in B by 120 deg. This means that we have a true "three-phase ripple" advancing in the same direction as the main wave, but with 13 times the velocity. Now, look at the 11th harmonic; in phase B it will be 2/3 period in advance of that in A; similarly C will be 2/3 period in advance of B. This, again, will form a "three-phase ripple," but retreating this time with 11 times the velocity of the main wave. What does this mean in the rotary converter? The armature is rotating, say, at n revolutions forwards; the three-phase current in it produces a backward rotating field of speed n relative to the armature, or at rest relatively to the field system. The 13th harmonic, travelling 13 times as fast and in the same direction, corresponds to a rotating field revolving at a speed of $(13 - 1)$ times that of the armature relative to the fixed position of the brushes, while the 11th harmonic produces a field rotating in the opposite direction, and therefore with $(11 + 1)$ times the speed of the armature relatively to the fixed frame of the rotary.

Both of these harmonics will therefore have the effect of producing 12 ripples per cycle in the D.C. voltage. The same argument could not be applied to the 17th, 19th, or any other harmonics; if, therefore, for any reason these predominate, we should expect the D.C. voltage line to be somewhat broken and jagged. In this connection refer to Curves X and XII, and compare also the undulating voltages.

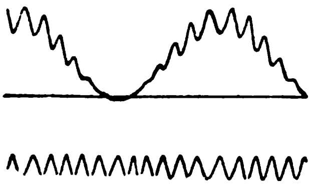
Again, if we assume that (due to the changing magnetic reluctance of the circuit as the pole assumes different positions relatively to the armature teeth) fluctuations in the total magnetism emerging from the polar surface are introduced, we can imagine that the field system is giving a rise to a constant, plus an alternating, flux. This alternating flux will have a frequency of q where $\sim$ equals the frequency of the generator. This alternating flux is, moreover, equivalent to two rotating fluxes rotating forwards and backwards with q times the velocity of the field system. If we add the rotation of the field system, we have a main or fundamental field rotating at, say, unit speed, a forward rotating field at $q + 1$, and a backward rotating field at a speed of $q - 1$. Hence variation of total flux will likewise give rise to the 11th and 13th harmonics.

We now come to the question of the magnification or accentuation of the harmonics. This can be brought about, in my opinion, in two entirely distinct and separate ways:—

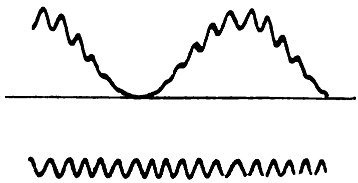
(1) By strongly magnetising the teeth in the armature by the armature currents themselves;

(2) By resonance, pure and simple.

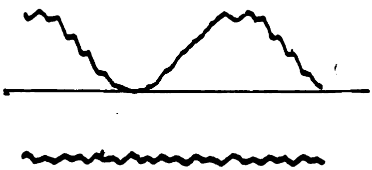
These two causes produce results of a very similar nature, but each phenomenon appears to require a totally different explanation.



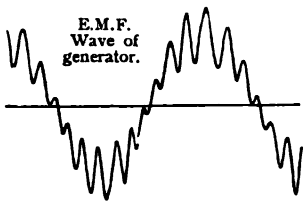
Curve X.—A.C. and D.C. E.M.F. of Rotary. Generator supplying 140 amps., lagging current.



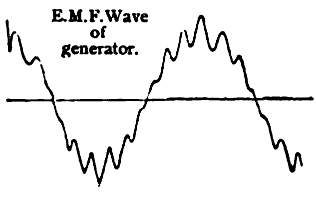
Curve XI.—A.C. and D.C. E.M.F. of Rotary. Generator supplying 25 amps., 7 rotaries running on no load, normal excitation, 93,700 yards of cable connected.



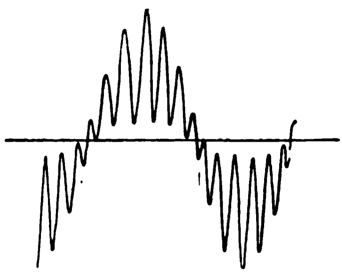
Curve XII.—A.C. and D.C. E.M.F.'s. One rotary running with normal excitation, 93,700 yards of cable connected.



Curve XIII.—Rotaries on no load, under-excited, 195 amps., lagging at power station.



Curve XIV.—Rotaries on no load over-excited, 185 amps., leading at power-station.



Curve XV.—E.M.F. Wave of Generator on no load, cables adjusted for partial resonance with 13th harmonic.

Examine Curves XIII., XIV., XV. In the first case, a lagging current,' nearly equal in amount to the full-load current of the generator, was being given out.

Now, a lagging current involves a very strongly-excited field system in the generator. The armature current will be of a demagnetising order, and will produc its maximum effect when the pole is in the

most favourable position for the magnetisation of the teeth within the coil.

A leading current, on the other hand, involves a weakly-excited field system, the armature currents augmenting the magnetism due to the field winding; again the pole is in a favourable position for the magnetisation of the teeth by the armature currents.

It appears, curiously enough, that the lagging current produces the greater magnification of the harmonics, but that practically the full-load current is necessary to produce this effect to any great extent. Turn now to Curve XV. A few cables only were in circuit, and the current flowing out of the generator was too small to be read on the station instruments. This was a case of resonance.

I would here ask pardon for digressing into the elementary theory of electrical resonance for the benefit of any present who may not have had occasion to consider the subject.

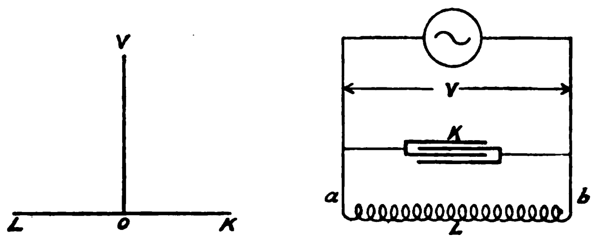


FIG. 7.

The current flowing into a condenser may be expressed in effective amperes by

$$2 \pi n \mathrm{K} \mathrm{V} \quad \ldots \ldots \ldots \ldots \quad (7)$$

where n = frequency of the circuit;
„ K = capacity of condenser in farads;
„ V = effective volts.

Again, if L be the coefficient of self-induction of a coil, the current passing through it will be expressed by

$$\frac{\mathrm{V}}{2 \pi n \mathrm{L}} \quad \ldots \ldots \ldots \ldots \quad (8)$$

V being the effective volts at its terminals.

If we equate (7) and (8) we get the condition under which the capacity current equals the self-induction current, V being the same in each case. This condition is

$$(2 \pi n)^2 = \frac{1}{\mathrm{L}\,\mathrm{K}}. \quad \ldots \ldots \ldots \ldots \quad (9)$$

Let us suppose that we have a pure self-induction and a pure capacity connected in parallel, as in Fig. 7.

Let the alternating E.M.F. V be represented by the vector O V; we know that the capacity current will be 90 deg. in advance of O V, that is

in position O K; we also know that current flowing through the self-induction will lag behind O V by 90 deg. This is represented by O L.

If now equation (9) holds, O K = O L, and the resultant of these currents as far as the outside circuit is concerned, is zero at every instant. We have then the case of a combination, of which the terminals are a and b; when this combination forms part of a closed circuit in which an alternating E.M.F., of frequency n and value v, is generated, no current circulates on the outside circuit $a\,c\,b$, and the potential difference between a and b is V. These are the conditions which would hold if the combination were removed and a perfect insulator substituted. We may therefore say that this combination at this particular frequency behaves, as far as the outside circuit is concerned, as a perfect insulator.

Now, introduce resistance r into each arm of the combination, and modify the diagram to suit, Fig. 8.

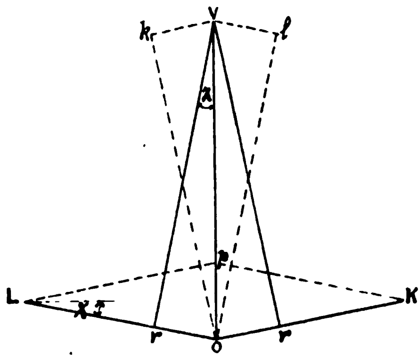


FIG. 8.

O L and O K will not now lag and lead by quite 90 deg.; in each case we have an ohmic drop O r in phase with the current, and an E.M.F. O l, O k at right angles, such that the resultant with the corresponding ohmic drop is O V.

The current in the outside circuit will be O p, which is equal to

$$2 \times \mathrm{O\,L} \sin \chi\,;\ \text{or}\ 2\,r\,\frac{\mathrm{O\,L}^2}{\mathrm{O\,V}}$$

and will be in phase with O V. The combination therefore will behave as though it had an ohmic resistance of

$$\frac{\mathrm{O\,V}^2}{\mathrm{O\,L}^2} \times \frac{1}{2\,r}.$$

Now, $\mathrm{O\,V}^2 = \mathrm{O}\,l^2 + \mathrm{O}\,r^2$; $\mathrm{O}\,l^2 = (2\,\pi\,n\,\mathrm{L})^2\,\mathrm{O\,L}^2$, and from (8) and (9) we can write $\frac{1}{\mathrm{L\,K}}$ for $4\,\pi^2\,n^2$,

hence $\mathrm{O\,V}^2 = \left(\frac{\mathrm{L}}{\mathrm{K}} + r^2\right)\mathrm{O\,L}^2$ ∴ the resistance is $\frac{\mathrm{L}}{2\,\mathrm{K}r} + \frac{r}{2}$.

Let us take an example and put $L = 1$ secohm, $K = 1$ microfarad, $r = 1$ ohm, then the resistance of the combination will be 0·5 megohm; thus we see that if the capacity and self-induction be not pure, but contain also a small amount of ohmic resistance, the combination behaves towards the outside circuit at the particular frequency as an imperfect insulator, but nevertheless of high insulation resistance. If in this particular case we make the further condition that

$$\frac{L}{2\,Kr} + \frac{r}{2} = r \text{ or that } K = \frac{L}{r^2},$$

the combination is equivalent to an effective resistance of r ohms, and this will as a matter of fact be true not only for sine waves of the one particular frequency, but universally for any periodic or unperiodic function which expresses the change of V; in fact, under these circumstances the current in the outside circuit is always V/r.

We have now to consider a perfect self-induction in series with a perfect capacity, and the same current C passing through each. This modifies the diagram shown in Fig. 7 somewhat.

If we turn O L through 90 deg. forward, the E.M.F. required to overcome self-induction will be O V_L; if we turn O K back through

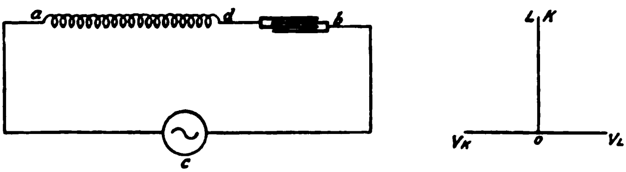


FIG. 9.

90 deg. to concide with O L, the voltage vector will take the position O V_K; see Fig. 9.

This diagram represents the state of things when the same current flows through capacity and self-induction, and the current is at its maximum.

If, therefore, the current is C, and is represented by the vector O L and O K, the potential difference between a and d will be the vector O V_L and between d and b the vector O V_K; therefore between a and b the potential difference will be the sum of O V_L and O V_K, which is at every instant zero. We are therefore sending a definite current through the combination, although no potential difference between the terminals a and b is necessary. The combination, therefore, behaves, as far as the outside circuit is concerned, at this particular frequency as a perfect conductor. I am indebted to Mr. R. C. Clinker for the notion of a perfect insulator and perfect conductor here introduced. The current strength in the circuit $a\,c\,b$ will be determined by the resistance of this portion of the circuit and the E.M.F. induced in it. If the resistance be low, the current will rise to a correspondingly high figure.

Now, although the potential difference between *a* and *b* is zero, we know that that between *a* and *d* or *d* and *b* is given by equations (7) and (8). Let us therefore imagine the E.M.F. E acting in the circuit, the self-induction short-circuited, and the current measured to be *c*; then, if the capacity be short-circuited instead of the self-induction, we shall have again the current *c* flowing.

If both be short-circuited we shall have a current of E/ρ where $\rho =$ resistance of portion *a c b*. Now, E/ρ may be 10, 100, 1000, etc., times *c*, just depending on the value of ρ. But if both self-induction and capacity remain unshort-circuited, the same current will flow as if short-circuited; hence, in the former case the potential difference *a d* or *a b* will be approximately 10, 100, 1000 times E, as the case may be, just depending on the ratio of E/ρ to *c*. This is what is known as electrical resonance, when the combination of self-induction and capacity acts like a perfect conductor, or a nearly perfect conductor, as far as the outside circuit is concerned, there being, however, a rise of potential within the combination equal to $C\sqrt{\frac{L}{K}}$.

Of course, if we consider the self-induction as possessing resistance *r*,

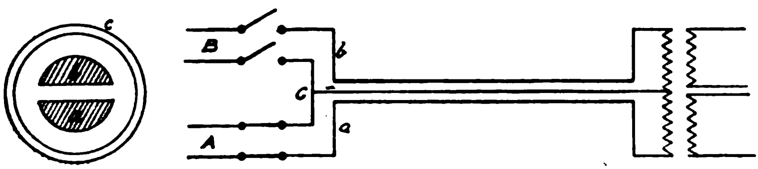


FIG. 10.

and the capacity also the same resistance, the combination will behave as an imperfect conductor with ohmic resistance $2r$ ohms, *i.e.*, the potential difference between *a* and *b* will be $2r$C and in phase with C.

In alternating electric supply circuits we often have to deal with self-inductions and capacities which would check the current down to the same values if the same E.M.F. were applied to each, which is the necessary condition for resonance; consider, for example, a two-phase cable with two insulated cores within a common outer as return; see Fig. 10.

Suppose phase B in the power-house has been opened, and consider the state of things that exists; we can represent it as shown in Fig. 11. Current enters conductor *a*, and returns by conductor *c*; it can flow through the capacity *a c*, and the self-induction *a c*, these being in parallel; but an alternative path is through capacity *a b*, and thence through capacity *b c* in parallel with self-induction *b c*.

Suppose the frequency is 25, the voltage per phase = 3000 volts, the transformers at the end of the line 150 kw. each, and such as to take a magnetising current of 2 per cent. of full-load current or one ampere; secondary circuits are open. Let the capacity between either conductor *a* or *b* and sheath, the other conductor being grounded

be ·75 mf. per mile, and between *a* and *b* together, and sheath ·9 mf. per mile, *i.e.* cap: $(a + c)$, b = ·75, and cap: $(a + b)$, c = ·9 mf. per mile, then we have a capacity effect equivalent to that shown in Fig 11. Let the length of line be 2·83 miles, then the total capacity $a\ c$, = 1·27 mf. and total capacity $a\ b$, = ·847 mf. If now the potential difference between *b* and *c* is V_1, the current through the transformer $b c$ is $V_1/3000 = 3{\cdot}33 \times 10^{-4}\ V_1$, and through the capacity $b\ c$, $2 \times 10^{-4}\ V_1$. The current arriving at *b* will therefore be a wattless current,

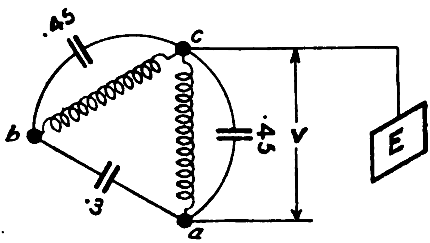


FIG. 11.

lagging 90 deg. between the E.M.F. and equal to 1·33 $10^{-4}\ V_1$. But if the difference of potential between *a* and *b* is V_1, we have again a capacity current through $a\ b$ of 1·33 $10^{-4}\ V_1$.

Thus we have the necessary conditions for resonance, and the potential of the switched-out conductor *b* will rise until the insulation somewhere in the cable gives way and modifies the conditions. This has merely been given as an example; there are, of course, a large number of combinations possible where resonance might occur, and

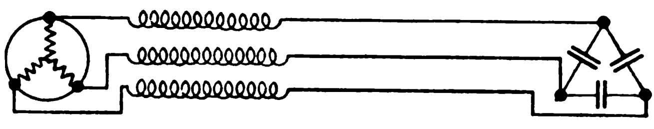


FIG. 12.

every station engineer is more or less on the alert for them. A most interesting paper on the subject of high-tension cable breakdowns from resonance effects appeared in the "Electrotechnische Zeitschrift" on 28th December, 1899, by Mr. Gisbert Kapp, and was translated by the present writer for the *Electrical Review*, and appeared in the 9th and 23rd March issues of that paper in 1900.

Now, every alternator possesses reaction and self-induction. By reaction I usually mean that the armature currents produce magnetic lines which thread through the magnetic path in the field system, either weakening or strengthening it, according as the armature ampere-turns assist or oppose the field system magnetising force. The term self-induction I usually apply to those lines of force generated by

the armature currents which do not produce an alteration of the total flux in the field system, but which close round the armature windings without including the field-magnet windings. Both of these effects are more or less proportioned to the strength of the armature currents, and result in an alteration of the magnetism threading the armature windings. This diminution or increase, as the case may be, induces an E.M.F. in quadrature with the current, and may therefore be looked upon as a self-induction.

Every alternator, therefore, may be represented by an imaginary machine producing an alternating E.M.F., without self-induction and without reaction, but with a choking coil in series with it. Unfortunately, as we shall see later, it is necessary to consider the choking coil as having a variable coefficient of self-induction, which is however, a periodic function of time. We may thus represent a three-phase alternator connected to a cable as in Fig. 12.

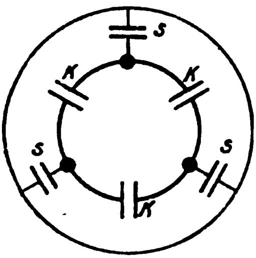


FIG. 13*a*.

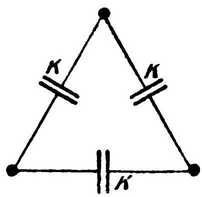


FIG. 13*b*.

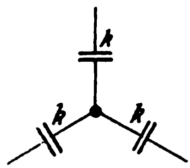


FIG. 13*c*.

In talking of the self-induction of an alternator, I shall for the purpose of this paper include in the term the armature reaction, *i.e.*, I shall refer to that self-induction (whether with constant or variable coefficient) which inserted in series with a reactionless and self-inductionless machine would give the same characteristics.

The capacity of a three-phase three-core lead-sheathed cable may be considered as a combination of capacities, as in Fig. 13 (*a*).*

A three-phase Δ capacity as shown in Fig. 13 (*b*) will take the same current per line wire as a Y capacity as in Fig. 13 (*c*) if $K = \frac{k}{3}$.

We do not in practice meet cases where the self-induction of

* We are justified in assuming the capacity effect of a multiple core lead-sheathed cable can be exactly represented by actual capacities between the individual conductors, and between the conductors and lead sheath, for taking the case of a three-core cable, we know that if Q_1 Q_2 Q_3, V_1 V_2 V_3 represent the charges and potentials of the various conductors, the lead sheath being grounded, we have the relations—

$$Q_1 = a_{1\text{-}1} V_1 + a_{1\text{-}2} V_2 + a_{1\text{-}3} V_3 \quad . \quad . \quad . \quad . \quad . \quad (10)$$

and similarly for Q_2 and Q_3, where the *a* coefficients are constants of the same dimensions as capacity.

Now, if we consider capacities $K_{1\text{-}2}$ $K_{1\text{-}3}$ $K_{2\text{-}3}$ connected between the con-

the alternator will produce resonance with the capacity of the cable system at the fundamental frequency. For example, taking a large three-phase cable system as represented by a three-legged capacity of 5 mf. per leg, the capacity current per leg at 6,500 volts per phase, 25 cycles would be 2·95 amperes. Fig. 14.

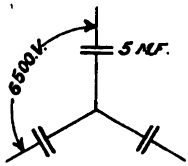


FIG. 14.

The self-induction in the alternator which would produce resonance with this cable system would therefore be such as would only allow 2·95 amps. per leg to circulate when the generator was excited to 6,500 volts, and short-circuited. Such an alternator would be manifestly inadequate in connection with such a cable system, but might perhaps

ductors, and $K_{1\cdot s}$ $K_{2\cdot s}$ $K_{3\cdot s}$ connected between the conductors and sheath, we have:—

$$Q_1 = K_{1\cdot 2}(V_1 - V_2) + K_{1\cdot 3}(V_1 - V_3) + K_{1\cdot s}V_1 \quad . \quad . \quad (11),$$

and similarly with Q_2 and Q_3.

This can be written as—

$$Q_1 = (K_{1\cdot 2} + K_{1\cdot 3} + K_{1\cdot s})V_1 - K_{1\cdot 2}V_2 - K_{1\cdot 3}V_3.$$

Hence
$$\begin{aligned} a_{1\cdot 1} &= K_{1\cdot 2} + K_{1\cdot 3} + K_{1\cdot s} \\ -a_{1\cdot 2} &= K_{1\cdot 2} \\ -a_{1\cdot 3} &= K_{1\cdot 3}, \text{ and so on.} \end{aligned}$$

We therefore see that (11) is only another way of writing (10); if then we determine $K_{1\cdot 2}$ $K_{1\cdot 3}$ $K_{1\cdot s}$, etc., by experiment, we can consider these as actual capacities connected as represented by eq. (11).

Owing to symmetry in a three-core cable we can write—

$$K_{1\cdot 2} = K_{1\cdot 3} = K_{2\cdot 3} = K$$
$$\text{and} \quad K_{1\cdot s} = K_{2\cdot 3} = K_{3\cdot s} = S.$$

Now, if 2 and 3 be earthed, we have—

$$Q_1 = (2K + S)V_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12).$$

If 2 and 3 be connected together but not earthed, and if they together have an equal and opposite charge to that on 1, we have—

$$Q_1 = (2K + S)V_1 - 2KV_2$$
$$Q_2 = (K + S)V_2 - KV_1 = -\frac{Q_1}{2}$$
$$\therefore \quad V_2 = -\frac{V_1}{2}, \text{ and } Q_1 = (2K + \frac{2}{3}S)(V_1 - V_2) \quad . \quad . \quad . \quad (13).$$

Lastly, if 3 be left insulated without charge, and if the charge on 2 be equal and opposite to that on 1, we have—

$$Q_1 = (2K + S)V_1 - K(V_2 + V_3)$$
$$V_2 = -V_1$$
$$\text{and} \quad O = (2K + S)V_3 - KV_1 - KV_2, \text{ i.e., } V_3 = O.$$

This gives—

$$Q_1 = (3K + S)V_1 = \left(\frac{3}{2}K + \frac{S}{2}\right)\left(V_1 - V_2\right) \quad . \quad . \quad . \quad (14).$$

If, therefore, we measure Q and the P.D. in any two of these cases, we have all particulars necessary for the determination of the capacity constants of the cable, and can treat these as if they were actual capacities connected as shown in Fig. 13(*a*), where the centre point is the lead sheath.

We shall have occasion to make use of (12), (13), and (14), a little later.

be used for applying a pressure test to the cables, in which case, of course, the greatest care would have to be exercised.

Although the self-induction of the supply alternator will not produce resonance at the fundamental frequency, it does not at all follow that such may not occur, due to a higher harmonic of the E.M.F. The current which a given capacity will take at a given voltage is proportional to a frequency, while the current which a self-induction will pass at the same voltage is inversely proportional to the frequency.

In the above case the capacity current per 1000 volts corresponding to the 11th harmonic would be 8·65 amps. A self-induction which would pass 8·65 amps. at 1000 volts 275 cycles per second would pass 356 amps. at 3,750 volts and 25 cycles, or an alternator with this self-induction per leg would give on short-circuit 356 amps. per leg when excited to 6,500 volts per phase. (I have chosen this figure, because it nearly corresponds with the results taken from the 2,500 kw. generators in Glasgow.) We should therefore at first sight expect to obtain resonance with such an alternator, and a cable system corresponding to Fig. 14, if an 11th harmonic existed in the E.M.F. wave.

I made some experiments to determine the capacity of the cables, by inserting a hot-wire ammeter in circuit, but I obtained strangely inconsistent readings; I therefore forbear to give them.

Mr. R. C. Clinker made some tests on similar cables for the Central London Railway, and obtained the following results per mile :—

1. From one core to other two cores + lead sheath = ·38 mf.

2. From one core to other two cores, sheath disconnected and earthed = ·32 mf.

3. From one core to one other core, 3rd-core insulated, sheath disconnected and earthed = ·23 mf.

If K be the capacity from core to core, and S the capacity from core to sheath, and assuming the insulation of both poles of the testing circuit to be so good that all leakage currents were negligible in comparison with the capacity currents, we see that we have :—

$$\text{By test (1) } 2K + S = \cdot 38$$
$$\text{,, } (2)\ 2K + \frac{2}{3}S = \cdot 32$$
$$\therefore S = \cdot 18 \qquad K = \cdot 1$$

and by test (3) we have a capacity of

$$\frac{3}{2}K + \frac{S}{2}.$$

Which with above values of K and S equals ·24 as against ·23 actually measured.

The above cable is therefore equivalent to a Y capacity of ·48 mf. per leg per mile, and therefore 10·4 miles would give the capacity represented in Fig. 14.

As a matter of fact, I find considerably more cable is needed to produce resonance, and I think this is probably due to the fact that the coefficient of self-induction of the alternator is by no means the same for the fundamental as for the higher harmonics.

We know that the coefficient of self-induction of such a machine varies between wide limits, it must depend on the relative position of field system to armature coils, and also on the value of the armature current in each position. Fig. 15 represents what is known as the curve of synchronous impedance of the Glasgow alternators; or the short-circuit armature current, in terms of armature volts on open circuit with the same field excitation at synchronous speed.

In the first place, it is clear that by this method the self-induction should be a maximum, since the poles are in the most favourable position when the armature currents are at their maximum. Next, we see that even this method does not give a constant coefficient. If we take the area of one-half period of the E.M.F. wave as proportional to the square root of the mean square, and the maximum of the current as proportional to the R.M.S., which would be correct

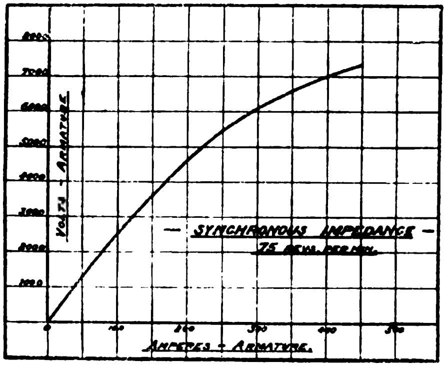


FIG. 15.

assumptions if we were dealing with sine functions, then the volts would be proportional to, or represent maximum flux, and current, the maximum current producing such flux, in which case the slope of the synchronous impedance curve represents $\frac{d\,\mathrm{N}}{d\,\mathrm{C}}$, where N is the total flux produced by the current C.

Now $\frac{d\,\mathrm{N}}{d\,\mathrm{C}} = \frac{d\,\mathrm{N}}{d\,t} \cdot \frac{d\,t}{d\,\mathrm{C}}$, therefore the slope which we will call $\tan\theta$ is such that

$$p \tan\theta \frac{d\,\mathrm{C}}{d\,t} = \frac{d\,\mathrm{N}}{d\,t} \left(\text{or } \mathrm{L}\frac{d\,\mathrm{C}}{d\,t} = \mathrm{E}\right),$$

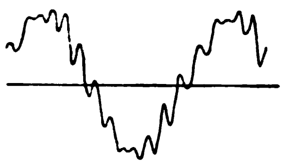
which means that $\tan\theta$ at every point of the curve is proportional to the coefficient of self-induction for that particular current strength.

Fig. 15 shows that this varies between the limits of 1·3 at low currents and 0·5 at 300 amperes.

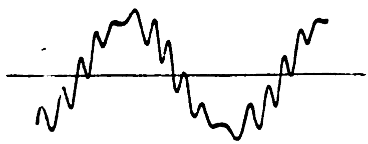
We see then that the coefficient of self-induction has a different value for each ripple on the E.M.F. wave, due to the position of

the field system; and, again, when a heavy armature current is being generated, the coefficient is further modified by the degree of magnetic saturation of the armature. The resultant of these two effects must depend largely on the power-factor of the circuit, and will be an extremely complicated function to express.

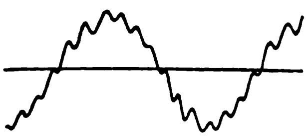
If we examine Curves XVI. and XVII. we see that with 93,700 yards of cable in circuit we obtain the 11th harmonic accentuated; with somewhat less cable in I have obtained resonance due to the 11th harmonic, but could not obtain a photographic record. Curves XVI. and XVII. were taken with about twelve months' interval. The first was traced by hand; the second photographed. I cannot vouch for the engine speed being exactly the same in each case. On reducing the capacity I brought the 13th harmonic gradually into prominence (see Curves XVIII., XIX., and XV.). It is very difficult



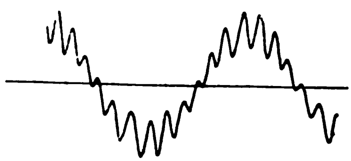
CURVE XVI.—No Load E.M.F. Wave. 93,700 yards of cable connected.



CURVE XVII.—No Load E.M.F. Wave. 93,700 yards of cable connected.



CURVE XVIII.—No Load E.M.F. Wave. 71,200 yards of cable connected.



CURVE XIX.—E.M.F. wave. 51,800 yards of cable connected.

to obtain good results under these circumstances, for if resonance be too pronounced the oscillograph motor stops, and the results cannot be noted. I do not think that Curve XV. shows the conditions of maximum resonance by any means; in fact, I have had instantaneous glimpses of alarming resonance, but for the reasons already stated I could not reproduce them.

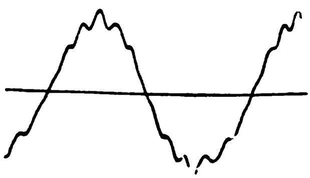
I used to think it a safe procedure when shutting down to gradually slow up the main engine and let the voltage die down gradually; similarly it was my opinion that one should excite the generator, and run up slowly on the cables when starting up, but from these experiments it is clear that by so doing one passes through the conditions for maximum resonance with all odd harmonics above the 11th. Undoubtedly the better procedure is to run the machine up to full speed, and then slowly to bring up the excitation to the normal, and to reverse the procedure when shutting down.

Curves XX. and XXI. more nearly approach to the E.M.F. curve of the alternator on open circuit.

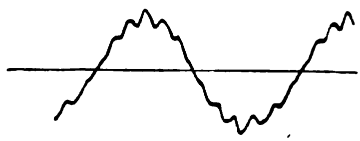
Another important point to consider is whether resonance due to a higher harmonic can occur under load conditions. The curves generally indicate that this is not so, the ripples being apparently damped down to a minimum under load conditions.

Curve XXII., which was taken at half normal load, shows, however, certain ripples accentuated, and the question is worth inquiring into.

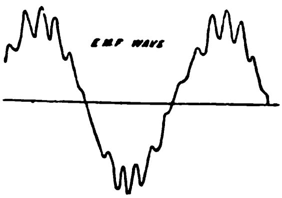
Look at Curve XXIII. We have already seen that the back E.M.F. of the rotaries being a smooth curve, the higher current harmonics in the system are wattless, and are either capacity or self-induction currents. The current ripples which flow into the rotaries, representing self-induction currents, no doubt partly neutralise the capacity of the system, but at the high frequencies



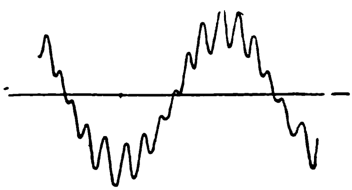
Curve XX.—No Load E.M.F. Wave. 9,150 yards of cable connected.



Curve XXI.—E.M.F. Wave. 2,290 yards of cable connected



Curve XXII.—Taken at substation C as load falls off between 11–12 p.m., 125 amps. at power-station.



Curve XXIII.—E.M.F. Wave Rotaries on no load (normal excitation), 20–30 amps. at power-station.

we are dealing with it is impossible that the whole capacity effect can be thus neutralised, and we have at such frequencies as 275 and 325 cycles a balance of capacity effect left over; it is then merely a question of the number of rotaries, transformers, and cables in service which decides whether or not partial resonance will occur under load conditions.

In this connection it must be borne in mind that if r is the ratio of transformation of the transformers (in the case in question $r = 20$), a coefficient of self-induction in the low-tension side is equivalent to r^2 ($= 400$) times the coefficient of self-induction in the high-tension side. When, again, we compare the capacity and self-induction currents (for the same voltage applied) at a high frequency, such

as the 13th, and remember that the former varies directly, and the latter inversely as the frequency; we see that even a large wattless current in the low-tension side, due to self-induction at the fundamental frequency, can have but a small effect in neutralising the capacity effect of the cables at the high frequency. This is easily calculated out.

From the foregoing, it is evident that it should be easy in any particular case to determine experimentally what conditions of capacity, etc., will give maximum resonance.

For example, if we know the length (l) of cable which produces resonance with the p^{th} harmonic, one generator only working, at the speed s revolutions per minute, we know that the length which will give resonance, with the q^{th} harmonic at a speed s, will be $l\left(\frac{p\,s}{q\,s_1}\right)^2$; again, if two generators be thrown in parallel, we halve thereby the inductance of the circuit, and therefore resonance with the same harmonic will only occur with twice the amount of cable connected to the circuit.

This fact alone will usually prevent important resonance effects under full-load conditions, the period of greatest importance from this point of view being that of light load, where the cable system is being fed from one generator which is perhaps of relatively small proportions.

It must not be supposed that I attach great practical importance to the above considerations of the possibility of the occurrence of resonance; as a matter of fact, although in Glasgow, I was for a long time unaware that anything of the kind could be going on, we experienced no difficulty at all, and it is the general opinion of a great many experienced engineers with whom I have spoken on the subject that resonance is not to be generally feared in ordinary well-laid-out systems.

I *do*, however, consider it important for each engineer, as far as possible, to be conversant with the conditions under which resonance is likely to occur in the system under his charge, and to avoid the combination if it is at all likely to be serious.

It is further conceivable that slight resonance effects might occur in cable circuits supplied by continuous-current machines. All such dynamos have a ripple of a high order present in their E.M.F. In the case of a rotary converter this ripple may, as we have seen, be pronounced, and I think it possible that considerable resonance effects might be found in such cases. It would be interesting to look for them.

PART II.

The second part of this paper is descriptive of some experiments I carried out to examine optically the more temporary or non-periodic effects in electric circuits, by which I mean such effects as the growth of the current in a continuous-current circuit containing self-induction, or the oscillatory nature of the charge current of a

cable when switching it on to a direct- or alternating-current circuit, and other similar effects. I am perfectly aware that these phenomena are treated mathematically in the various text-books on the subject, but I still think the experiments highly instructive.

In order to render these results visible on the desk of the oscillograph, it was necessary to make them occur periodically and synchronously with the motor of the oscillograph. I therefore constructed a contact maker, and attached it to the shaft of a disused tramway motor, which had already been provided with two slip rings for other purposes. The motor was supplied with direct current, the oscillograph motor connected to the slip-rings, and the strips suitably connected to the contact maker. The latter consisted of a continuous ring, and a second one cut into sixteen equal parts

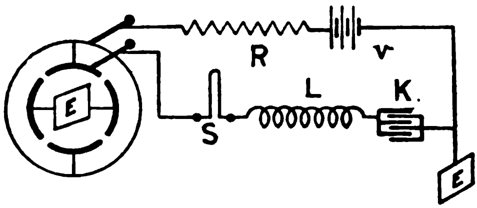


FIG. 16*a*.

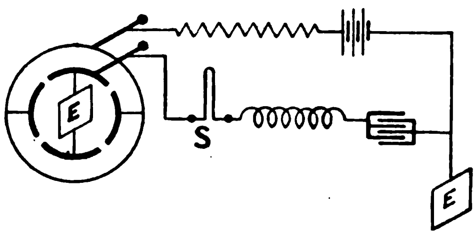


FIG. 16*b*.

with provision for connecting them up in any way desired. The motor having four poles, I connected the contacts in four groups of four, and used this arrangement throughout.

Figure 16 (*a*) and (*b*) shows my general arrangement.

In position (*a*) it will be seen that the charge current for the combination of capacity and self-induction passes through the oscillograph strip S; in position (*b*) the combination discharges through S; this process, occurring synchronously with the vibrations of the oscillograph mirror, appears as a stationary curve and can be photographed as heretofore. The photographs, which I here reproduce, had an average of 30 seconds exposure.

Curve XXIV. represents an ordinary make and short-circuit without self-induction or capacity.

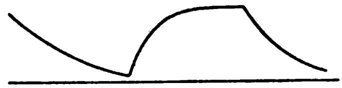
Curve XXV. represents the growth of the current in a circuit containing a transformer on open circuit.

Curve XXVI. represents the above, but with half of the high-tension winding short-circuited through a single lamp.

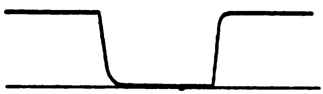
Curve XXVII. represents the same, but with the whole high-tension winding short-circuited through the incandescent lamp.

The annihilation of the self-induction due to the short-circuited secondary is noteworthy. I have used the curves thus photographed for the determination of the coefficient of self-induction of a circuit;

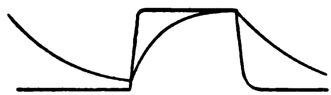
CURVE XXIV.—R = 24·25 ohms, L = O, K = O, R.P.M. = 750, V = 2·6 volts.



CURVE XXV.—R = 24·4 ohms, L = transformer H.T. open, K = O, R.P.M = 760, V = 3·9 volts.



CURVE XXVI.—Same as XXV., but with half H.T. winding short-circuited.



CURVE XXVII.—Same as XXV., but with whole of H.T. winding short-circuited.

it will be noticed it gives the value of the coefficient of self-induction for practically zero current, since the current through the oscillograph should at no time exceed 0·1 ampere. As such, the method may prove useful to others who have an oscillograph at their disposal, and I will therefore illustrate it briefly.

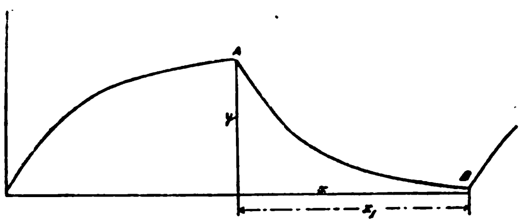


FIG. 17.

We know that the law of curve from A to B, Fig. 17, is

$$y = k\epsilon^{-px},$$

y and x representing distances only, and being measured to the same scale.

We have then that $\frac{d(\log_\epsilon y)}{dx} = -p$; in other words, if we measure y for each value of x from the curve, and plot $\log_\epsilon y$ and x to the same scale, we should obtain a straight line not passing through the origin, and with a negative slope equal to p.

But we know that $p\,x_1 = \frac{R}{L} t_1$*; t_1 being the time occupied by the discharge from A to B. $\therefore$ L in secohms $= \frac{R\,t_1}{p_1\,x_1}$
R being in ohms, and t_1 in seconds.

t_1 is of course easily determined by the speed of revolution of the contact maker. In my experiments, t_1 was $\frac{1}{60}$th second. It is to be noticed that the constant of the oscillograph or deflection per ampere does not enter in.

It may be urged that where y is very small it will not be possible to measure it accurately. This is true; the curve of discharge is really asymptotic to the zero line, log 0 equals $-\infty$, hence if we take the zero line the smallest amount too high or too low we should get, on

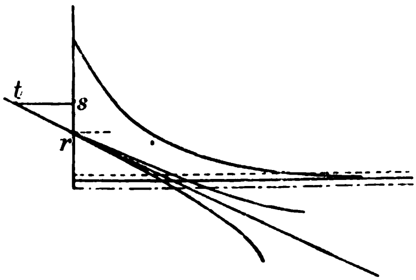
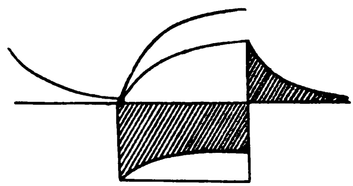


FIG. 18.



CURVE XXVIII.—Shaded Area defines V during charge and discharge.

plotting logarithms, curves either running out to infinity within a finite time or becoming parallel to the zero line (see Fig. 18).

We can get over this difficulty in the following way. We know y measured from the true zero is $k\epsilon^{-px}$. Let us write y_0 measuring from false zero as $M + k\epsilon^{-px}$, then

$$\frac{d\,(\log_\epsilon y_0)}{d\,x} = \frac{-\,p\,k\,\epsilon^{-px}}{M + k\,\epsilon^{-px}} = -\,p\,\frac{y}{y_0}$$

that is measuring the slope of the logarithmic curve reckoned from the false zero line gives us an inaccurate result in the ratio of y to y_0 at the point in question. It is clear then that the logarithmic curve will become more and more nearly straight as it approaches the vertical axis of y, if therefore it be produced and the slope measured at this point we know the error should not be more than $\frac{y}{y_0}$ at the origin, which in my opinion might easily be kept down to within 1 per cent.

If before drawing the logarithmic curve we multiply our log y values by $\frac{x_1}{t_1}$, then the slope will be such that if we mark off on the vertical axis $r\,s$ to represent R in ohms, $s\,t$ will represent L in secohms.

* $\frac{R}{L}\,t$ is a mere numeric; the dimensions come out $M^0\,L^0\,T^0$.

Curves XXVIII. and XXIX. represent the way the potential rises at the terminals of a self-induction shunted with a resistance greater than its own when the circuit is ruptured; the connections were made as in Fig. 19, the curves explain themselves.

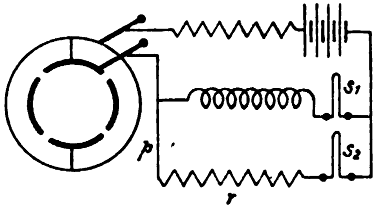
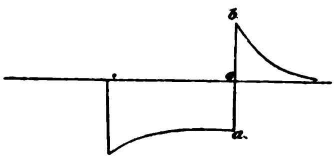


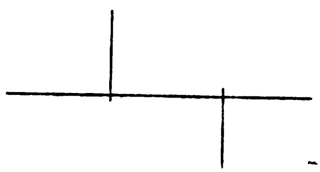
FIG. 19.

The strip S_2 being connected across the self-induction as shunt really acts as a voltmeter. When the discharge takes place the same current flows through each strip, the rise of voltage is therefore represented by $Ob—Oa$; Oa representing the voltage at the instant before discharge. Of course, by making r large enough the potential across the self-induction might be brought up to any value provided the circuit be ruptured with absolute suddenness, *i.e.*, no spark occur at break, and there be no eddy currents induced anywhere by the circuit. These conditions are, of course, impossible, but it is well known that there is really no absolute limit to the rise of potential on rupturing a circuit possessing self-induction.

We now come to the oscillatory charge and discharge currents in circuits containing self-inductions and capacities. These experiments were made as indicated in Fig. 16. and are represented in Curves XXX.–XXXVI.



CURVE XXIX.—Taken from Curve XXVIII. ob–oa represents rise in voltage on opening circuit.


CURVE XXX.


CURVE XXXI.


CURVE XXXII.

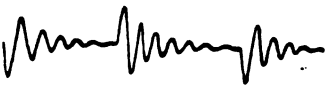
In the first series we start with capacity only; the charge and discharge are so rapid that the oscillograph apparently overshoots the zero line.

The exponential term in this case is $\epsilon^{-\frac{1}{KR}t}$ In my experiments the capacity was $1{\cdot}5 \times 10^{-6}$ farads, and resistance roughly 25 ohms. The maximum self-induction coefficient was approximately ·33 secohm (it was a variable self-induction depending on the current strength), the

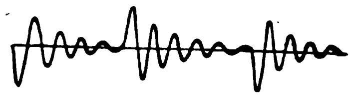
combination therefore had a natural frequency of about 225 cycles per second.

We see then that $\frac{1}{KR} = 2{\cdot}67 \times 10^4$, and $\frac{R}{L} = 75$, that is the process depicted in Curve XXV. as happening in $\frac{1}{30}$th second, occurs in Curve XXX. in $\frac{1}{17800}$th second. Under these circumstances the natural frequency of the oscillograph strips will, of course, come into play.

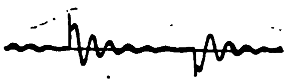
Curves XXXI.–XXXIV. represent the oscillations in the self-same circuit, as the self-induction is gradually increased. It is to be noticed throughout that the resistance in circuit on discharge is always less than that on "make." An examination of Fig. 16 will show that this is the case.



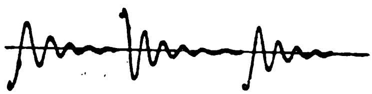
CURVE XXXIII



CURVE XXXIV.



CURVE XXXV.



CURVE XXXVI

Curves XXXV.–XXXVI. were taken with exactly the same apparatus, with the exception of the self-induction. Here a different transformer was used. I reproduce them on account of the irregularities at "make" and discharge. I cannot quite account for this. I certainly had some leakage effects going on in the circuit, but they did not seem able to account for this initial irregularity. There was another abnormality which I noticed on closing the circuit; there was an instantaneous oscillatory curve depicted very much larger than the permanent ones. It was merely instantaneous. This, again, may have been a charge leaking into the condenser in some way, but I had no time to investigate it fully. Perhaps the mathematicians will tell me if some other effect is possible, and, if so, it would be well worth while to try and repeat it, and investigate the matter further.

Curves XXXI.–XXXVI. show distinctly how rises of potential occur on switching cables either on to direct- or alternating-current machines.

The curves themselves are curves of current, but we know that the curve of E.M.F. across the condenser is of the same shape but displaced in phase, the maximum of E.M.F. occurring when the current is zero.

In this case it is easy to see that the maximum voltage across the condenser will reach nearly twice the steady value, thus:—

At the moment of closing the switch the current is zero, therefore the ohmic drop is zero.

The charge in the condenser being zero, v is likewise zero (see Fig. 20). The supply E.M.F. V must therefore be counterbalanced by a back E.M.F. in the self-induction due to the growth of the magnetic flux.

Now the voltage across the self-induction is $(V - v)$, but since $C = K \frac{dv}{dt}$, and at zero time $C = O$, we have at the moment of closing the switch the voltage across the self-induction or $V - v = V$ and $\frac{d(V-v)}{dt} = o$; this means that this voltage starts at its maximum value, viz., V. If we subtract V and reverse, we get the voltage across the condenser or v. The oscillations of v and c are shown in Fig. 21.

We see then at an instant after the start or at the end of the time of one-half oscillation the voltage v has risen up to nearly twice V. The voltage across the cable therefore oscillates about the constant value V, and finally settles down to that steady value. As there are a number of important particular cases where such oscillations arise in general practice, I will here state a few using a minimum of mathematical symbols.

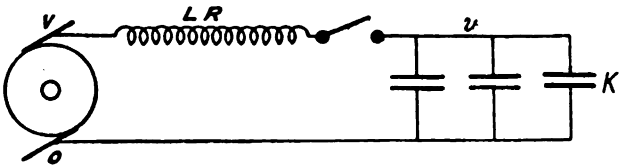


FIG. 20.

The differential equation which holds for case in Fig. 20 is of the familiar form—

$$\frac{d^2 v}{d t^2} + \frac{R}{L}\frac{d v}{d t} + \frac{v}{L K} = \frac{V}{L K} \quad . \; . \; . \; . \; . \; . \; . \; . \; (15)$$

Now, in the cases we are about to consider, V may have a constant value, and the equation applies to the charge portion of curves XXXI.–XXXIV.; V may be zero, as in the case of the discharge portions of the same curves; or V may be a sine function of the time, or

$$V_0 \sin 2 \pi n t.$$

In the first case we know the general expression

$$v = V + A \epsilon^{-\frac{R}{2L}t} \sin \left\{ \sqrt{\left(\frac{1}{LK} - \frac{R^2}{4L^2}\right)} t + \phi \right\} \quad . \; . \; (16)$$

satisfies equation (15).

If, however, $\frac{1}{LK}$ is $\overline{\overline{<}}\ \frac{R^2}{4L^2}$ the discharge is no longer oscillatory and we shall not consider these cases.

A and ϕ are constants depending on the particular conditions of the problem which must be fulfilled.

If V is zero, the solution (16) may still be applied.

If $V = V_0 \sin 2\pi n t$, we know that the final state at which the voltage v will arrive will likewise be a sine function. We can write down this final state as

$$v = \frac{V_0 \sin 2\pi n t}{L K \theta^2 + R K \theta + 1} \quad \ldots \ldots \ldots \quad (17)$$

Where θ* represents the operator $\frac{d}{dt}$; we will express this function as $v = v_0 \sin(2\pi n t + \phi')$.

A general solution which will be applicable to the initial as well as the final state of things will therefore be—

$$v = v_0 \sin(2\pi n t + \phi') + A\epsilon^{-\frac{R}{2L}t} \sin\left\{\sqrt{\left(\frac{1}{LK} - \frac{R^2}{4L^2}\right)}\, t + \phi\right) \quad (18)$$

The current, or $K\frac{dv}{dt}$ will in this case be represented by the expression—

$$C = 2\pi n K v_0 \cos(2\pi n t + \phi') + \frac{AK}{\sqrt{LK}}\epsilon^{-\frac{R}{2L}t}$$

$$\cos\left\{\sqrt{\left(\frac{1}{LK} - \frac{R^2}{4L^2}\right)}\, t + \phi + \tan^{-1}\sqrt{\frac{R^2 K}{4L - R^2 K}}\right\} \quad (18a)$$

The first expression representing the final state, and the latter the initial disturbance.

We shall have occasion to make use of this result later.

We will now, however, make a small digression, and briefly examine the nature of the oscillation represented by—

$$v = A'\epsilon^{-at} \sin \beta t \left\{ \begin{array}{l} \text{where } a = \dfrac{R}{2L} \\ \text{and } \beta = \sqrt{\dfrac{1}{LK} - \dfrac{R^2}{4L^2}} \end{array} \right.$$

We will take the case where the voltage across the condenser follows this law.

The coefficient A will, in lieu of a better term, be called the coefficient of the oscillation. v will be zero when $\beta t = n\pi$, or when $t = \frac{n\pi}{\beta}$; n being any integer. The successive zero values, therefore occur after equal intervals of time, viz., $\frac{\pi}{\beta}$.

The maxima will occur when $\frac{dv}{dt} = o$;

but $$\frac{dv}{dt} = -\frac{A}{\sqrt{LK}}\epsilon^{-at} \sin\left(\beta t - \tan^{-1}\frac{\beta}{a}\right).$$

Hence the maxima occur when

$$t = \frac{n\pi + \tan^{-1}\frac{\beta}{a}}{\beta}$$

* See Perry's "Calculus for Engineers."

This shows that the successive maxima occur after equal intervals of time, viz., $\frac{\pi}{\beta}$, but they do not necessarily occur exactly in the middle of the time-interval between the two successive zero values. Since the current through the condenser $= K\frac{dv}{dt}$, it is clear that the zero values of the current occur simultaneously with the maximum values of the voltage across the condenser.

The maximum values of the current occur when $\frac{d^2v}{dt^2} = o$, or when

$$\frac{A}{LK}\epsilon^{-\alpha t}\left(\sin \beta t - 2\tan^{-1}\frac{\beta}{\alpha}\right) = o$$

i.e., when $t = \dfrac{n\pi + 2\tan^{-1}\frac{\beta}{\alpha}}{\beta}$

The current maxima therefore do not necessarily occur simultaneously with the zero values of v.

If, however, $\frac{R^2}{4L^2}$ may be neglected in comparison with $\frac{1}{LK}$,

$$\tan^{-}\frac{\beta}{\alpha} = \frac{\pi}{2}$$

and we can represent the current by the expression—

$$\frac{AK}{\sqrt{LK}}\epsilon^{-\alpha t}\cos \beta t,$$

in which case the maxima occur half-way between the zero values, and the current maxima occur simultaneously with the zero values of v.

Further, in this case and with the oscillation $A\epsilon^{-\frac{R}{2L}t}\sin \beta t$ the absolute maximum occurs after time $\frac{\pi}{2\beta}$, the value being—

$$A\epsilon^{-\frac{\pi}{4}\sqrt{\frac{R^2K}{L}}},$$

and in the case of the oscillation $A\epsilon^{-\frac{R}{2L}}\cos \beta t$, the absolute maximum will be equal to the coefficient of the oscillation, viz., A, *i.e.*, the oscillation starts at its absolute maximum.*

* The oscillation represented by $v = A\epsilon^{-\alpha t}\cos\left(\beta t - \tan\frac{\alpha}{\beta}\right)$ has zero slope $\left(\text{or } \frac{dv}{dt} = o\right)$ when $t = o$. This is the true form of the oscillation which starts at a maximum value, viz., $A\frac{\beta}{\sqrt{\alpha^2 + \beta^2}}$. Where, however, $\frac{R^2}{4L^2}$ may be neglected $\tan^{-1}\frac{\alpha}{-} = o$, and the maximum or initial value is A.

In the cases we shall consider here $\frac{R^2}{4 L^2}$ is negligible with regard to $\frac{1}{L K}$, so that we may apply the above simplifications, and write as the frequency of oscillation—

$$\frac{1}{2\pi}\sqrt{\frac{1}{L K}}$$

There are two rules which it is of importance to keep in mind on account of their bearing on the voltage and current rises in alternating-current circuits when oscillations are started. They are as follows :—

(1) If in a circuit consisting of a capacity and a self-induction a voltage oscillation be started of which the initial maximum value is v_0, the coefficient of the current oscillation will be—

$$\frac{C_0\sqrt{\frac{1}{L K}}}{2\pi n}$$

where C_0 is the maximum value of the condenser current after the steady state has been reached if the voltage $v_0 \sin 2\pi n t$ is applied at its terminals.

(2) If a current oscillation be started of which the initial maximum value is C_0, the coefficient of the corresponding voltage oscillation will be—

$$\frac{v_0\sqrt{\frac{1}{L K}}}{2\pi n}$$

where v_0 is the maximum value of the voltage wave which must be applied to the terminals of the self-induction in order that the current, after the steady state has been reached, may be of the shape $C_0 \sin 2\pi n t$.

$$\frac{\sqrt{\frac{1}{L K}}}{2\pi n}$$

represents, of course, the ratio of the frequency of the oscillation to the frequency of the supply circuit. These rules are the obvious outcome of what has preceded.

We will now return to the treatment of the case where, say, a cable is switched on to a D.C. generator which possesses self-induction. v is represented by equation (16).

At time $t = o$ we have to satisfy the conditions $v = o$ and $\frac{d v}{d t} = o$ or $C = o$.

The first of these conditions results in the equation $V = -A \sin \phi$, and the second shows us that at time o the oscillation starts at maximum or crest.

The frequency of oscillation will be—

$$\sqrt{\frac{1}{L K} - \frac{R^2}{4 L^2}};$$

the time occupied by a half oscillation will be—

$$t = \frac{\pi}{\sqrt{\frac{1}{LK} - \frac{R^2}{4L^2}}}$$

$$\therefore \text{ at time } t = \frac{\pi}{\sqrt{\frac{1}{LK} - \frac{R^2}{4L^2}}}$$

$$v = V + A\epsilon^{-\frac{R}{2L}\cdot\frac{\pi}{\sqrt{\frac{1}{LK}-\frac{R^2}{4L^2}}}} \sin(\phi + \pi)$$

$$= V\left(1 + \epsilon^{-\frac{\pi}{\sqrt{\frac{4L}{R^2K}-1}}}\right) \quad \ldots\ldots\ldots\ldots (19)$$

and this will be the maximum value to which the E.M.F. across the cable can rise.

At the limit $\frac{4L}{R^2K} = 1$, which is the limit at which the current ceases to be oscillatory, $v = V$ and there is no rise of voltage.

We cannot take a negative value for the $\sqrt{\ }$ term in equation (19), for taking the negative value of the square root gives a result for something that was happening before we began to count time. It has no meaning except in the case of an oscillation having been started, and the zero of time being taken at some period subsequently.

We can therefore dismiss this case. The value of the exponential in (19) must therefore be between 1 and 0. We have discussed the latter condition. The former is attained when $\frac{1}{R^2K} = \infty$. Therefore when R or K is very small, or when L is very large, v will rise to a maximum of practically twice V.

It is interesting to think of the case where a voltage V is suddenly applied to one end of a coil of large self-induction and low resistance, the other end being free. The interruption in the circuit is equivalent to a very minute capacity. An extremely rapid oscillation will then be set up through the coil, and the potential at the free end will oscillate about a mean V with an extremely high frequency, the oscillation continuing for an appreciable time. We are now getting into the range of the wireless telegraphist. In the case of a cable being switched on to an alternator we may apply the self-same result if the circuit be closed at the maximum of the E.M.F. wave, and this be sufficiently flat or the oscillation sufficiently rapid for us to assume that there is no appreciable diminution of the E.M.F. during the time of one-half oscillation. In this case we may say the maximum voltage will be nearly twice V, and under other conditions less.

If the cable be already charged and have a potential difference at its terminals of $-V$, and be switched on to a circuit of P.D. $+V$, the maximum to which it can be subjected will be nearly 3 V.

It will be seen at once in the case of a steady voltage V, and it can be shown to be equally true in any other case, that provided R is small in comparison with $2\pi n L$ in Fig. 20, the voltage across L due to the

oscillation is at every instant equal and opposite to v, hence we have the same condition as that for resonance during the steady state, viz., that a current flowing through a self-induction in series with a capacity produced a P.D. across the former equal to that across the latter, but opposed in direction. In these initial stages we are therefore also dealing with resonance effects, the difference between that, where we have a steady state of resonance, we have to adjust L and K so that $\frac{1}{2\pi} \cdot \frac{1}{\sqrt{LK}}$ corresponds to the frequency of the supply circuit. During the unsteady state we have resonance with any values of L and K, for given an initial pulse of E.M.F. or current, the frequency of oscillation (n_1) will be self-adjusting so that still $2\pi n_1 = \frac{1}{\sqrt{LK}}$. If the circuit in Fig. 20 be closed when the E.M.F. is zero, the steady state is not instantly reached, for this would imply that the current into the cable was very nearly at its maximum value, but we know that it will be zero. We have therefore to consider the expotential term in equation (18).

The conditions we have to satisfy are, at time

$$\begin{aligned} t = 0 \qquad & V = 0 \\ & v = 0 \qquad \text{and } \frac{dv}{dt} = 0 \\ & C = 0 \end{aligned}$$

The first condition is already satisfied where $V = V_0 \sin 2\pi n t$.
The second involves $v_0 \sin \phi^1 + A \sin \phi = 0$ . . . . (20)
The third involves—

$$2\pi n K v_0 \cos \phi^1 + \frac{AK}{\sqrt{LK}} \cos \left\{ \phi + \tan^{-1} \left(\frac{\alpha}{\beta}\right) \right\} = 0 \quad . \ (21)$$

These conditions merely state that the initial value of the voltage and current oscillation are equal and opposite to the values of voltage and current which exist after the steady state has been reached at the moment of the E.M.F. wave when V passes through the zero.

We can of course solve equations (20) and (21), and obtain A and ϕ in terms of v_0 and ϕ^1 which again are determinable from equation (17).

But in the case under consideration we can cut this short in the following manner :—We know that the P.D. across the self-induction (which is the self-induction of the generator) is practically directly in line with V, in other words $\phi^1 = 0$, and therefore also $\phi = 0$. There is still another condition which must be true at time $t = 0$. We know that at every instant the P.D. across the self-induction $= V - v$, but $(V - v)$ may be expressed as :—

$$L \frac{dC}{dt} + RC,$$

at time $t = 0$ this is also zero, and therefore if R is small in comparison with L (which is the case with every alternator) we may say $\frac{dC}{dt} = 0$ at zero time.

This last condition shows us that at the moment of starting, the

current oscillation has its *maximum* value, which is equal and opposite to $2\pi n K v_0$. We may therefore say at once that the coefficient of the oscillatory voltage is—

$$v_0 \frac{2\pi n}{\sqrt{\frac{1}{LK}}}$$

This will be a very small oscillation which starts when v_0 is zero; the rise of voltage across the cable will therefore be very small if switched in at the moment of zero E.M.F., but there will be a current oscillation of which the initial value equals the maximum value after the steady state has been reached.

I do not propose to lengthen out this inquiry by going into other more complicated cases, such as switching on cables with transformers connected across the ends, or switching on circuits to generators already loaded on other circuits, since in no case are greater rises

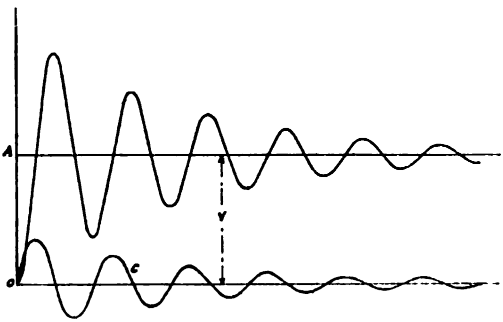


FIG. 21.

of potential called into existence by initial disturbances than those we have already considered.

I will therefore take up the special case of switching off a cable circuit already loaded with a highly inductive circuit, such as lightly loaded transformers, or worse still, a circuit opening on the high-tension side, the low-tension circuit being loaded on an inductive load.

Two limiting cases are those of special interest—(1) When the circuit is broken at the moment the current is passing through zero; (2) when the circuit is broken at the instant the current is at its maximum.

Dealing first with the case of a bank of transformers, the secondary of which is on open circuit.

Let the maximum of the charging current of the cable be C_K and of the transformers C_L, then we have the relations—

$$C_K = 4\pi^2 n^2 L K C_L \text{ and } 2\pi n L C_L = v_0$$

If the circuit be opened at the moment the current C_K and C_L are

zero, the voltage being v_0 or the maximum of the steady state, it is clear that there will be excited a voltage oscillation starting with a maximum value of v_0. The coefficient of the current oscillation will be $\sqrt{\frac{K}{L}}v_0$, that is to say, the coefficient is to C_K in the ratio of the frequency of oscillation to n; and to C_L in the inverse ratio. There will, however, be no rise of voltage.

If the circuit be opened when C_L and C_K are at their maximum values, or when the voltage is zero, a current oscillation will be excited starting with the maximum value C_L.

The coefficient of the voltage oscillation will then be $\sqrt{\frac{L}{K}}C_L$, that is to say, the coefficient is to v_0 in the ratio of the frequency of oscillation to the frequency n. This will, of course, usually result in a considerable rise of potential. If the secondary, however, be not an open circuit, it may act more or less as a short-circuited turn and either damp down the violence of the oscillation if the secondary circuit be non-inductive, or increase the violence of the same if the load be very inductive. In any case the effect of the

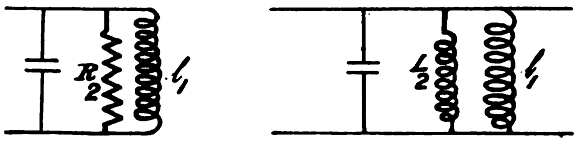


FIG. 22.

secondary may be represented by a shunt circuit in the primary, thus in Fig. 22, l_1 represents a choke coil having the same self-induction coefficient (l_1) as the primary circuit of the transformer on no load. R_2 L_2 represent the resistance or self-induction, as the case may be, which, when connected in parallel with l_1 will behave, as far as the supply circuit is concerned, as does the transformer on load. If the transformer supplied motors, it would be necessary to include in the shunt circuit a back E.M.F. Taking the worst case, where the secondary circuit is loaded inductively at the moment of interrupting; it is clear that during the oscillation that follows the total energy of the system will be at one instant stored electro-magnetically in the magnetic field interlinked with the circuit, at another electro-statically in the capacity.

The total energy at the moment of interrupting is

$$\frac{1}{2}Kv^2 + \frac{1}{2}l_1\left(C_1 - \frac{\sigma_2}{\sigma_1}C_2\right)^2 + \frac{1}{2}LC_2^2,$$

the first term representing the total energy stored in the capacity in watt-seconds at the moment of interrupting, K being the capacity and v the voltage at the terminals at the moment in question; the second term being the watt-seconds stored in the transformer due to its

magnetic state, C_1 C_2 being the primary and secondary current at the moment of interrupting, and σ_1 σ_2 the number of turns of primary and secondary respectively; while the last term represents the energy stored electro-magnetically in the secondary external circuit; L being coefficient of self-induction of this external circuit.

The maximum value of the voltage oscillation will be slightly less than V, where

$$V = \sqrt{v^2 + \frac{l_1}{K}\left(C_1 - \frac{\sigma_2}{\sigma_1}C_2\right)^2 + \frac{L}{K}C_2^2}.$$

This, of course, is readily calculable; it will represent a very considerable and usually a highly destructive rise of potential.

As a last example of the kind, we will consider the oscillation in a circuit consisting of a capacity and self-induction, where at the moment of the interruption the voltage across the capacity is $-v_1$, and the current flowing through the self-induction is C_1.

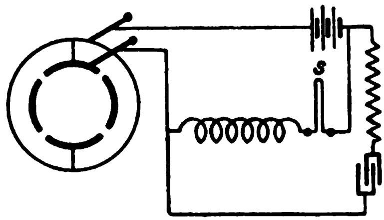


FIG. 23.

We can consider the voltage oscillation as the resultant of two components, the first given by the conditions when $t=o$, $v=o$, $C=C_1$, the second given by the conditions when $t=o$, $v=-v_1$, $C=o$. It is clear that the sum of these oscillations will satisfy the fundamental equation, and the initial conditions, viz., when $t=o$, $v=-v_1$, $C=C_1$.

We have, however, already considered both components separately, and can write down the oscillations forthwith in their approximate forms, as :—

$$v = -v_1 \epsilon^{-\frac{R}{2L}t} \cos\left(\sqrt{\frac{1}{LK}}\right)t + C_1\sqrt{\frac{L}{K}}\,\epsilon^{-\frac{R}{2L}t}\sin\left(\sqrt{\frac{1}{LK}}\right)t$$

$$C = v_1\sqrt{\frac{K}{L}}\,\epsilon^{-\frac{R}{2L}t}\sin\left(\sqrt{\frac{1}{LK}}\right)t + C_1\epsilon^{-\frac{R}{2L}t}\cos\left(\sqrt{\frac{1}{LK}}\right)t,$$

or—

$$v = \sqrt{v_1^2 + C_1^2\frac{L}{K}}\,\epsilon^{-\frac{R}{2L}t}\sin\left\{\left(\sqrt{\frac{1}{LK}}\right)t - \tan^{-1}\frac{v_1}{C_1\sqrt{\frac{L}{K}}}\right\}$$

$$C = \sqrt{v_1^2\frac{K}{L} + C_1^2}\,\epsilon^{-\frac{R}{2L}t}\cos\left\{\left(\sqrt{\frac{1}{LK}}\right)t - \tan^{-1}\frac{v_1}{C_1\sqrt{\frac{L}{K}}}\right\}$$

I could have obtained these results by means of the oscillograph had I thought my capacities would have stood the severe strain.

The connections would have been as in Fig. 23. The current curve

through S would then be of the nature shown in Fig. 24. If we make the resistance in the battery circuit one-half that in the condenser circuit, we have the exponential terms during both charge and discharge operations the same; in other words, the curve representing the oscillation will be found to just fit into the cone formed by taking two of the curves A B C, representing the charge period. This is shown dotted in the diagram.

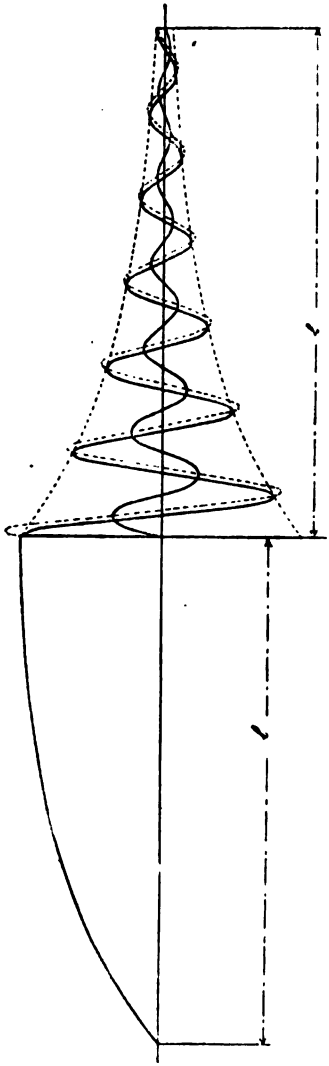


FIG. 24.

A few words with regard to the frequency of oscillation of which we have been speaking.

A 5,000-volt cable of such length as to give 1 microfarad capacity connected to a transformer of which the magnetising current was 1 ampere at 50 ∿, or with an L of 15·9 secohms, would resonate with a frequency $\frac{1}{2\pi}\sqrt{\frac{10^6}{15{\cdot}9}}$ or 40 cycles per second. A generator on the other hand which would give a short-circuit current of 200 amperes, or with an L of $\frac{15{\cdot}9}{200}$ secohms would produce an oscillation of frequency of $40 \times \sqrt{200} = 560$. In large systems the oscillations produced on switching on cables to their generator will usually be of a much higher order than those produced in the system on switching off.

PART III.

We have up to the present assumed that, provided the 3-phase system be symmetrical, the capacity effect of the cables may be exactly reproduced by substituting in place of the cables conductors without capacity, but with a single combination of capacities

connected between them and earth, as represented in Fig. 14. We know, however, that this is not strictly true; a 3-core cable really can only be represented by a distributed capacity, as in Fig. 25, where A B C represent the 3 cores, and the dotted line an imaginary earthed conductor of zero resistance. Now, if in this case an E.M.F. be suddenly applied at one end of the cable, the other being open-circuited, the whole cable does not become instantly charged; *i.e.*, the current at the point p_1 in core A will have a different value from that at point p_2 at every instant. Further, the potential at p_1 above earth will not be the same as that at p_2, and the quantity of electricity charging the cable per cm. length at p_1 will be different from that at p_2.

On the other hand a definite and appreciable time will be necessary for the charge to be felt all along the cable.

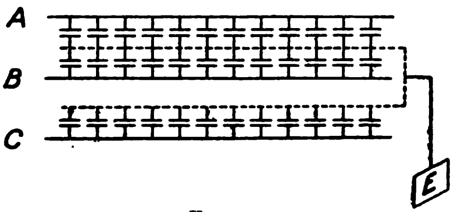


FIG. 25.

We have, in fact, the same sort of problem as that of sending signals through the Atlantic cable, where, if a pulse of E.M.F. or current be injected into the cable at one end, an appreciable time is required before the pulse is manifested at the far end.

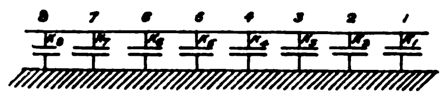


FIG. 26.

What goes on may be briefly stated to be as follows:—

If at any instant the potential at 1 (Fig. 26) is zero, and current is flowing from 2 to 1, the potential at 2 will be positive, which means that the capacity k_2 must have a definite charge while that of k_1 is zero.

Again, if current is flowing from 5 to 4 to 3 to 2, the potential at 5 will be higher than 4, of 4 than 3, of 3 than 2; hence the charge in k_5 is greater than that in k_4; of k_4 than k_3; of k_3 than k_2. Now every capacity takes an appreciable time to charge, and, therefore, there will be a time-growth of charge along the cable, k_1 arriving at its full charge last.

Now let us assume that by the time k_1 has received a definite charge the potential at the sending end has been gradually reduced to zero; the charge in the initial capacity will then be zero, and in the final capacity k_1 a maximum. We have then the exact reverse of the initial state when the charge in k_8 was a maximum and in k_1 zero. There will now be a return current tending to equilibriate the potential along the conductor. This return or reflected wave will require a definite time interval to reach the sending end, and if the applied E.M.F. at the sending end is periodic, and the returning waves synchronise with the applied periodic E.M.F., a state of resonance will be set up. This might reach dangerous proportions,

a small E.M.F. at the sending end involving an extremely high P.D. at the far end.

I have worked out this case for a 3-core cable, with an impressed E.M.F. at one end, consisting of a fundamental of 25 cycles and a 13th harmonic; but find that the length of cable required before a dangerous state of resonance is set up is far beyond anything at present in use in this country for power transmission purposes. I do not propose to give the full mathematical details of this problem as they may be found elsewhere.

As, however, this particular case of the general problem is interesting to electrical engineers, I propose to apply here the solution of the same to a practical case.

We will confine our attention to a 3-core lead-sheathed high-tension cable; area per core = ·2 □″

Let ρ = resistance of 1 core per mile = ·22 ohm.

Let κ = equivalent capacity per leg per mile (see Fig. 14) = ·5 × 10^{-6} farads.

Let λ* = coefficient of self-induction per core per mile (*i.e.*, λ is a coefficient such that volts drop in *each* core per mile $= \rho\, c + \lambda \dfrac{dc}{dt}$).

Let c be the current at any point and at any time, flowing axially along the conductor under consideration.

Let v be the potential above earth at a similar point.

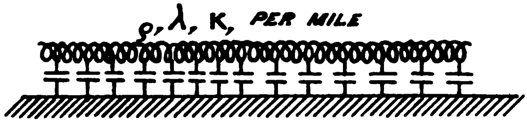


FIG. 27.

We need only consider one core, and may think of it as consisting of a conductor as represented in Fig. 27.

The cable is on open circuit at the far end; at the near end a sine wave of E.M.F. is applied.

The fundamental differential equations of the problem are:—

$$\frac{d^2 v}{d x^2} = \rho\kappa \frac{dv}{dt} + \lambda\kappa \frac{d^2 v}{d t^2} \quad . \quad . \quad . \quad . \quad . \quad (22)$$

$$\frac{d^2 c}{d x^2} = \rho\kappa \frac{dc}{dt} + \lambda\kappa \frac{d^2 c}{d t^2} \quad . \quad . \quad . \quad . \quad . \quad (23)$$

$$\frac{dc}{dx} = -\kappa \frac{dv}{dt} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (24)$$

* I here represent resistance, coefficient of self-induction, and capacity per unit length, by Greek letters, as these quantities are of different dimensions from the R L K previously employed; we saw that $\sqrt{\frac{1}{LK}}$ was of the dimensions of a frequency or $\frac{1}{T}$, we soon shall see that $\sqrt{\frac{1}{\lambda\kappa}}$ represents a velocity or $\frac{\text{length}}{T}$. It is of importance, in order to avoid a confusion of ideas, to keep this point well in mind.

A solution for v is—

$$v = V_0 \epsilon^{ax} \sin (2 \pi n t + a x),$$

and for current—

$$c = C_0 \epsilon^{ax} \sin (2 \pi n t + a x + \psi).$$

These solutions would apply to the case of a cable infinitely long; we have, however, to satisfy the terminal conditions—

$$\begin{aligned} &\text{when } x = o, v = V_0 \sin 2 \pi n t, \\ &\text{when } x = l, c = o, \end{aligned}$$

l being the length of the cable in miles.

The particular solutions which satisfy these terminal conditions are:—

$$\begin{aligned} v = {} & V_1 \epsilon^{-ax} \sin (2 \pi n t - a x + \phi) + \\ & V_1 \epsilon^{-a(2l-x)} \sin (2 \pi n t - a(2 l - x) + \phi) \end{aligned}$$

$$c = \frac{2 \pi n \kappa V_1}{\sqrt{a_1^2 + a_1^2}} \left\{ \begin{aligned} &\epsilon^{-ax} \sin (2 \pi n t - a x + \phi + \theta) - \\ &\epsilon^{-a(2l-x)} \sin (2 \pi n t - a(2 l - x) + \phi + \theta) \end{aligned} \right\}$$

$$\begin{aligned} \text{where } \quad \mathrm{a} &= \sqrt{\pi n \kappa (\mathrm{I} - 2 \pi n \lambda)} \\ a &= \sqrt{\pi n \kappa (\mathrm{I} + 2 \pi n \lambda)} \\ \mathrm{I} &= \sqrt{\rho^2 + 4 \pi^2 n^2 \lambda^2} \\ V_1 &= \frac{V_0}{\sqrt{1 + \epsilon^{-4al} + 2 \epsilon^{-2al} \cos 2 a l}} \\ \tan \theta &= \frac{\mathrm{a}}{a} \\ \tan \phi &= \frac{\epsilon^{-2al} \sin 2 a l}{1 + \epsilon^{-2al} \cos 2 a l} \end{aligned}$$

An examination of the form of the solution of v and c shows that each consists of an original plus a reflected wave. If the cable had a length of $2 l$, then the first term gives the value of the original wave at, say, the point p_1; the second the value of the same wave at point p_2 (Fig. 28), and the solution tells us that in the case of the cable of length l, the actual value of the wave at p^1 is in the case of the E.M.F. the sum of the value at p_1 and p_2 at every instant; in the case of the current the actual wave at p_1 is the difference between the values at p^1 and p_2.

It will be noticed that the differential equations (22), (23), (24), which obtain for the case in question involve three conditions:—

(1st) If we consider any particular short portion of a given cable such as a b, the quantity of electricity entering this portion axially at a in a given time is equal to the quantity leaving axially at b, plus the accumulation of electricity at the side walls bounding the portion a b.

(2nd) The accumulation of electricity as above is equal to the pressure obtaining at the portion of the cable a b, multiplied by a constant depending on the nature of the containing walls, and not on the conductor. If this constant is zero there can be no accumulation, and the quantity entering *a* equals the quantity leaving at *b*. The above, which merely state the electrical conditions, are obviously those for an incompressible fluid flowing through a pipe with elastic side-walls. For if the side-walls be rigid there can be no accumulation in any portion of the tube; if elastic, the quantity entering any cross-section such as *a* equals that leaving another cross-section *b*, plus the accumulation in the portion *a b*, this accumulation taking place in virtue of the elasticity of the side-walls, and *not* being due to any compressibility of the fluid itself.

The 3rd condition is that the potential gradient at any moment and at any cross-section is the sum of two factors—the first proportional to the quantity per second passing the cross-section at that

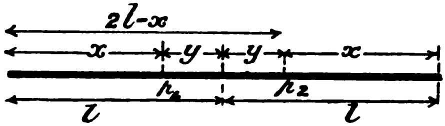


FIG. 28.

moment, and second proportional to the quantity per second per second or the acceleration.*

This last condition would similarly hold for a fluid possessing inertia, and being retarded in its passage by true fluid friction (*i.e.*, loss of head $\propto$ velocity). Now all these three conditions will very nearly obtain in the case of water flowing through an indiarubber tube. This is a most useful analogy to fix our ideas of what goes on in a cable. (It will be noticed that the analogy of an organ pipe which has been proposed is quite inaccurate, for in this case we should be dealing with a compressible fluid in a pipe with rigid containing walls.) I should like to see a model made consisting of a suitable elastic tube with a blind end in which was included a small reciprocating pump. In this way we should be able to follow the propagation and reflection of the waves, also the propagation of individual wave fronts, a most important point which we shall touch on later. It is to be observed that the hydrostatic pressure at any portion of the tube corresponds to the electric potential at any portion of the cable, while the velocity of the fluid corresponds to the current strength.

We shall obtain maximum resonance when $a\,l = \frac{\pi}{2}$; or when $l = \frac{\pi}{2a}$.

* The equation representing this in the electrical case will be

$$\frac{dv}{dx} = \rho c + \lambda \frac{dc}{dt}.$$

In this case the E.M.F. at the sending end will be of effective value V_0; and at the receiving end—

$$\frac{2\epsilon^{-\frac{\pi}{2}\tan\theta}}{\sqrt{1+\epsilon^{-2\pi\tan\theta}-2\epsilon^{-\pi\tan\theta}}}\,.\,V_0$$

$$\text{or}\quad \frac{2\epsilon^{-\frac{\pi}{2}\tan\theta}}{1-\epsilon^{-\pi\tan\theta}}\,.\,V_0$$

We will apply these conclusions to the case of a 50 cycle circuit, containing a 13th harmonic or where $n = 650 \sim$ λ can be calculated from the formula—

$$^{*}\,\lambda = \left(\log_\epsilon \frac{b}{a} + \frac{1}{2}\right) 10^{-4} \times 3{\cdot}22$$

where b = distance between cores, a = radius of each core.

Let us take a = ·275 □″ b = ·8″, then λ per core per mile = ·000502 secohm.

If we say roughly that at this frequency $2\pi n\lambda = 10\rho$

$$\therefore \frac{a}{\alpha} = \sqrt{\frac{1-2\pi n\lambda}{1+2\pi n\lambda}} = \tfrac{1}{10}\text{ approx.}$$

$$\text{and}\quad \frac{2\epsilon^{-\frac{\pi}{2}\tan\theta}}{1-\epsilon^{-\pi\tan\theta}} = 12{\cdot}7.$$

It follows then that 13th harmonic will be magnified 12·7 times at the end of the cable.

Putting in the above values of ρ, κ, and λ in the expression $\frac{\pi}{2\alpha}$ we have $l = 23{\cdot}5$ miles.

It appears, therefore, it is quite within the region of possibility for this class of resonance to occur on a system of moderate frequency, supplying very long cables, and with slotted armatures containing two or more slots per pole per phase. This case, though of importance

* This formula gives half the value of the self-induction of a circuit made up of two parallel wires. In the 3-phase case the current in core 1 is at every instant equal to the sum of the currents in 2 and 3. Now, the effects of the currents in 2 and 3 on 1 will be independent of their relative positions, provided their radial distance from 1 is not changed—we can therefore consider them coincident, and calculate the effect on 1 as in the single-phase case. We may consequently take the self-induction of a loop with the same current per line as in 1, halve it and consider this the E.M.F. of self-induction acting in each of the line wires 1, 2, and 3 at right angles to the currents in those line wires. It is interesting to note that this formula will give the same result per line wire as if we calculate the self-induction of the inner of a concentric cable, the inner being of the same diameter as each core in the 3-phase cable, and the radius of the outer being the same as the distance between centres of the three individual cores, provided this dimension is large in comparison with the radial thickness of the outer conductor.

in electrical engineering, and deserving of careful consideration, need not necessarily cause uneasiness.

The value of the P.D. due to the harmonic at any intermediate point of the cable will lie between V_0 and $12{\cdot}7\ V_0$.

It is well known that the capacity effect of these long cables can be imitated almost perfectly by connecting up a number of smaller capacities with wire containing resistance and self-induction, and I suggest it would be a subject of vast interest if some one would investigate this matter experimentally rather than mathematically.

It is to be noted that since $\frac{2\pi}{a}$ is the wave length of the space wave in the cable, the velocity of propagation is $\frac{2\pi n}{a}$; when dealing with such high frequencies that we can afford to neglect ρ, $a = 2\pi n\sqrt{\lambda\kappa}$, and the velocity of propagation becomes $\sqrt{\frac{1}{\lambda\kappa}}$ miles per second.

If $\lambda = 5 \times 10^{-4}$, and $\kappa = {\cdot}5 \times 10^{-6}$; $\sqrt{\frac{1}{\lambda\kappa}} = 63{,}200$ miles per second, or approximately $\frac{1}{3}$ the velocity of light.

There is still an important aspect of the subject of High Potential Rises in circuits containing distributed capacity, self-induction, and resistance (and every circuit does to a greater or less extent) which I have not touched upon. I refer to the initial disturbances in such circuits when the potential at any one point is suddenly altered. The subject is a very difficult one to treat mathematically in at all a general manner; it must therefore be experimentally investigated. I doubt even if the oscillograph will be of much aid here on account of the extreme rapidity with which the phenomena take place.

A most interesting paper on the subject, entitled "Static Strains in High-Tension Circuits and the Protection of Apparatus," was read by Mr. Percy H. Thomas before the American Institute of Electrical Engineers, 14th February, 1902, which is well worth study by all who are interested in the subject. I am under the impression (I hope I am mistaken) that the Proceedings of the American Institute of Electrical Engineers are not read on this side with the attention they deserve, and I will ask pardon for briefly explaining here the nature of the so-called "Static Strains" of which the above-referred-to paper treats.

In Fig. 29, S represents a source of high potential (V). A B, a circuit or line of any nature at zero potential.

At the instant before closing the switch, the potential is represented by the full black line in Fig. 30. Now on closing the switch the line A B cannot, as we have seen, be instantly raised to the potential V; in fact, at the moment of closing, the potential (assuming no spark occurs) all along the circuit would likewise be represented by the full line in Fig. 30. Instantly, however, the charge in the portion of the system S T begins to distribute itself over the whole system from S to B, the first effect being a tendency for the electro-static charges in the neighbourhood of the switch to equalise themselves, resulting in a moderation of the steepness of the potential line, as shown dotted in Fig. 30.

This potential "front" will then travel along the system to B, becoming modified as it proceeds, depending on the constants of the line and circuit. The question is, what is the potential gradient at all parts of the circuit as this potential "front" reaches them? It is a question of vast moment. Every one who has worked much with high-tension motors and transformers will have experienced difficulty owing to the short-circuiting of turns and layers in a most curious way. I have seen the winding stripped off high-tension motors, the insulation of which

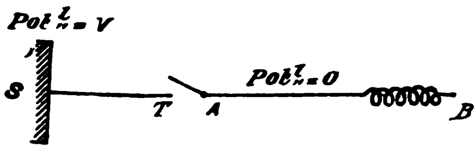


FIG. 29.

was punctured with innumerable pinholes. The normal voltage between turns is a perfectly definite quantity, and accounts in no way for the puncturing. But it is clear that if a potential front with a steep potential gradient traverses the winding, the potential difference between neighbouring windings or layers may be very excessive in comparison with that after the normal steady state has been reached. For example, if the distance a in Fig. 30 represents the length of two layers, it would be possible to have momentarily the full potential of the circuit across these layers.

On switching a high-tension motor on to a circuit, both poles cannot be closed simultaneously. On closing the first pole we have the state of things already discussed and represented in Fig. 30. The potential front on reaching the dead end of the circuit is reflected back, there

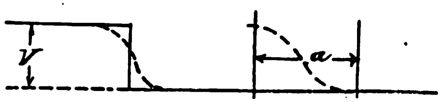


FIG. 30.

occurs, one may almost say, a "splash" of potential, possibly analogous to the splash caused by a sea wave on reaching a boundary wall, and similar to the reflected waves we have already discussed.

The same thing will occur on closing the second pole of the circuit, only in this case the height of the potential front will be twice what it was in the preceding case.

It is, of course, difficult to say whether the strain on the insulation is greater in this case than in the preceding; in general, we may say that if the front extends over a distance of more than two layers of the winding, the strain will be determined by the potential gradient.

These potential fronts may be created at any point of the circuit by suddenly altering the potential at that point, *e.g.*, by short-circuiting grounding, and the like.

This is a subject that will amply repay any one who will undertake a careful research.

In conclusion I should like to state how very powerful a weapon in experimental research Mr. Duddell's oscillograph should prove. There are a vast number of investigations, of which the above are but unhappy samples, which would amply repay any experimenter to carry out. It is only given to mathematicians to see clearly with the mind's eye the full physical interpretations of their symbols; to ordinary engineers, such as myself, who make no pretensions to wielding the mathematical weapons, an optical investigation of such phenomena brings home in a clearer way than pages of mathematics what is really going on. I would suggest that the study of the effect of an arc on opening a high-tension circuit, what goes on in sparks, in so-called liquid capacities such as are used for starting single-phase motors, determining the hysteresis loops of transformer circuits from the load current and voltage curves, and a number of other equally interesting and instructive series of experiments which suggest themselves at once, would form the ground-work for most delightful papers.

These subjects are, moreover, of the greatest commercial importance. Take, for example, the breaking of a high-tension cable circuit in air or in oil, and trace out the rises of potential in the two cases. At first sight one would think the air-break would be best; it is not so, but quite the reverse. What effect has the air arc then on the circuit?

I wish now to acknowledge the very considerable help my former assistant, Mr. S. Blackley, has rendered me in connection with the oscillograms here reproduced. It has meant many a night till 2 or 3 a.m., when after a hard day's work he has given up his spare time and devoted himself to the work with the spirit of an enthusiast. I wish also to express my indebtedness to Dr. Magnus Maclean for the help he has given me in the preparation of this paper.

Professor Magnus Maclean.

Professor MAGNUS MACLEAN wished to compliment Mr. Field on the excellence of his paper submitted, both from an experimental and mathematical point of view. It was a paper with which he was more or less familiar, as Mr. Field was kind enough to show him many of the experiments some time ago, and the theories put forward and the inferences deduced were mutually discussed on several occasions. There were many points in the paper to which he would like to refer, but, as the evening was far advanced, he would confine himself to the investigation which Mr. Field gave to prove that the 11th and 13th harmonics are the most important.* The way in which he showed that an 11th and a 13th could be inferred from the 12 ripples observed in the direct-current voltage was most ingenious, original, and, he thought, correct.

But he did not think that Mr. Field was justified in stating as he did

* It would be more in accordance with ordinary notation and nomenclature to call the term containing a frequency eleven times the fundamental frequency the 10th harmonic, and to call the term containing a frequency thirteen times the fundamental frequency the 12th harmonic. Thus with frequencies 1, 2, 3, 4, . . etc., 2 is the first harmonic, 3 the second harmonic, . . . etc.

Professor Magnus Maclean.

that these harmonics are the most important. As a matter of fact, the mathematical equation from which he deduced this result was an assumed equation: and if one assumed a corresponding equation like $a(1-\cos 6kt)$, it would follow by the same reasoning and the same nomenclature that the 5th and the 7th frequencies would be the most important. To find by the usual analysis whether lower harmonics were present or not, Professor Maclean got Mr. Blackley to magnify four of the curves by means of a pantagraph. These magnified curves were not very accurate, especially at the ripples, which were much sharper than they should be. This was due, as Mr. Blackley explained to him, to a sticking of the pantagraph. However, he thought they were accurate enough to enable him to find if there were terms containing 3 or 5 times the fundamental frequency. The enlarged curves were XV, XVII, XX, and another not given in the paper, but similar to XXI. He would call it XXI. He only had time to try the last three mentioned curves, and these only for frequencies 3, 5, and 11 times the fundamental. As terms containing even multiples of the fundamental frequency cannot appear in these curves, the general equation is :—

$$f(E) = E_1 \sin pt + E_3 \sin(3pt + \theta_3) + E_5 \sin(5pt + \theta_5) + \ldots$$
$$\ldots + E_{11} \sin(11pt + \theta_{11}) + E_{13} \sin(13pt + \theta_{13}) + \ldots$$

The process of finding E_1 E_3 E_5 . . . etc. is well known. It simply consists for finding E_3 in dividing the whole curve into three equal parts, superimposing these three parts and finding a third of the resultant ordinates at each point of the abscissæ. If this is a sine curve, its maximum ordinate is E_3. Again, to find E_5, divide the whole curve into five equal parts; superimpose these parts and find a fifth of the algebraic sum of the ordinates at each point of the abscissæ. If this curve is a sine curve its maximum ordinate is E_5. The others, E_7 E_9 . . . etc., can be similarly dealt with.

Due to a fault in the oscillogram, as mentioned in the paper by Mr. Field, the distance 0 to π is not equal to the distance π to 2π. Hence, when looking for frequencies 3 and 5, he divided 0 to π into 30 equal parts, and also π to 2π into 30 equal parts. This gave him twenty readings for the curve containing frequency 3, and twelve readings for the curve containing frequency 5. None of the curves gave any indication that a frequency 3 was present, but they all showed frequency 5 quite pronounced; and considering the inaccuracy of the curves analysed, the curves obtained in each case were fairly good sine curves. He now tried for E_{11} by dividing each half of the curve into 33 equal parts, giving him 6 points on the curve. All the three curves showed frequency 11 very good. He had no time to try for any of the others. The results he obtained were in arbitrary units :—

Curve XVII.	Curve XX.	Curve XXI.
$f(E)_{max} = 38{\cdot}7$	$f(E)_{max} = 42{\cdot}0$	$f(E)_{max} = 34$
E_5 ,, $= 2{\cdot}7$	E_5 ,, $= 1{\cdot}2$	E_5 ,, $= 1{\cdot}4$
E_{11} ,, $= 0{\cdot}9$	E_{11} ,, $= 1{\cdot}8$	E_{21} ,, $= 4{\cdot}2$

He thought Mr. Field was quite correct in his main conclusions about the 11th and 13th, but he did not think he was correct in ignoring the

Professor Magnus Maclean.

other harmonics. Indeed, in Curve XVII., the fourth harmonic is more important than the 10th, though the reverse is the case in Curve XXI.

In subtracting the harmonics so found from the original curve, it is quite obvious that there are more harmonics in each of them than the fourth and tenth. He believed from the appearance of them that there are more harmonics than the fourth, tenth, and twelfth, but he had had no time to work further at the curves.

Professor A. Jamieson.

Professor ANDREW JAMIESON said that any one who had carefully studied such books as "The Alternate Current Transformer in Theory and Practice," by Prof. Fleming, and the second or latest enlarged edition of "Alternate Current Working," by Prof. A. Hay, the mathematical parts of Mr. Field's paper were simple, clear, and explicit. Since he was dealing with actual concrete examples, the meaning of several of the formulæ were applied in a more telling manner, than will be found in most treatises upon alternate-current testing and working. Mr. Field had explained by blackboard sketches, in a clearer and more detailed manner than that stated in the proof copy of his paper, the principle, construction, and action of Duddell's oscillograph. He had also dwelt upon its capabilities and shortcomings, and pointed out how he overcame some of its defects. He might explain why he did not photograph the various waves of E.M.F. and current straight from the beam of light *as reflected directly* by the mirror which is fixed to the two phosphor-bronze strips (upon, say, a moving cinematograph film) instead of using the reflections from a second mirror, vibrated synchronously with the first one, but at right angles to its axis? Was there no possibility of an error arising from the use of this special motor and two such mirrors?

Passing over the points touched upon by the previous speakers, and referring at once to the condenser effect produced by electro-static capacity of the underground main high-tension cables, between the power-house and the sub-stations, they found the well-known formula (7) so familiar to submarine cable electricians, viz.:—Current, $C = 2 \pi n K V$. Then came equation (8), when a current was passed through a coil having a coefficient of self-induction L, where current $C = \frac{V}{2 \pi n L}$. And, when these were equated under the conditions stated, we got $(2 \pi n)^2 = \frac{1}{L K}$.

Now, as to a mere matter of history, he had had the pleasure of conducting a series of experiments, not only with Thomson and Jenkin's curb-sender, but also with Count Sicardi's curb-signalling key, leaks, and other methods. The object of these experiments was to find out if such devices minimised the retarding effects of electro-static capacity, and thereby increased the speeds of signalling through the long submarine cables of the Eastern Telegraph Co. There, of course, the capacity effects were very much more pronounced than in the case of the short main cables experimented upon by Mr. Field, but the frequencies and the voltages were very much less. However, the increased speeds so obtained by sending a reverse current after each signalling current,

Professor A. Jamieson.

although apparent, did not justify the permanent introduction of any of these methods, since Muirhead's duplex system and Ben. Smith's manual translation, which came to the front about the same time—viz., 1876 to 1878—showed better commercial results.* Then came Prof. S. P. Thompson's proposal to introduce into the cable circuit, at stated intervals, a certain anti-capacity effect by means of self-induction coils. His idea consisted of arranging and fixing these coils to the cable conductor, so that their self-induction should exactly or partially cancel the electro-static capacity effects of the cable. But this bold proposal did not meet with the approbation of practical cable engineers and electricians, owing to the mechanical difficulties of lowering such watertight coils to the bottom of the ocean whilst paying-out the cable, and of maintaining them in good electrical condition. He thought, however, that this plan could be successfully applied to long subterranean telegraph, telephone, alternate-current lighting, or power transmission cables. Mr. Field had shown how capacity and self-induction might be so joined and adjusted, that the opposition to the current was merely like that of a true ohmic resistance. But, then, his subterranean cables were easily got at; and if ever the "resonance effect" should prove troublesome, or from prior investigation of the conditions should appear to be in any way dangerous, the land electrician could easily make suitable provision against the same.

It was a pity that Mr. Field was leaving Glasgow, because if he had continued his experiments with the oscillograph and tried it directly at the central station, the Section would in all probability have either had a fresh paper or an appendix to his present long and weighty one, stating whether or not the capacity of even two- or three-mile lengths of the Glasgow tramway mains, between the central powerhouse and any of the sub-stations, did appreciably tone down the wave forms, as illustrated in the diagrams placed before us. He (Professor Jamieson) thought the author had said, that he had not come across a case wherein the resonance effect had proved dangerous to such cables. He was under the impression that the first subterranean cables put down at Londonderry, had been punctured or their insulation resistance seriously diminished by some such action. With such a splendid field for research, he hoped that the Glasgow Tramways'

* [I think that electricians who have opportunities of experimenting upon long submarine cables or artificial lines should carefully study Mr. Field's paper, as well as the experiments by F. Dolezatek and A. Ebelinz on the "Pupin System" of long-distance telephony (see *Electrician*, April and March, 1903). They should then try and devise the simplest and best combination of oscillograph and cinematograph for delineating the curves of charging and discharging or of signalling and of receiving currents, under a great variety of conditions. They could vary the internal resistance and E.M.F. of their sending batteries, the resistance and sensitiveness of their receiving instruments, the capacities of their sending and receiving condensers, the periods of curbing currents, the effects of introducing "Pupin Coils," etc. By trying and systematically comparing the photographic curves derived from these various changes upon cables of different lengths with different ratios of capacity and resistance per naut, they would have a much more searching and surer means of arriving at correct views upon the possibilities of increasing speeds of signalling, than by any of the older methods hitherto adopted.—A. JAMIESON.]

Professor A. Jamieson. oscillograph would not be allowed to rest in its instrument case, but that it might be still further skilfully applied to investigations such as had now been suggested. It could not be placed in better hands than one or other or both of the previous speakers, who would undoubtedly start fair and square at once at the very fountain-head, where only the full pressures of 6,500 volts were to be found! They must not, however, forget to *earth* the centre or neutral point of the armature; for it would be very sad to have to mourn their "loss."

At page 681, Mr. Field says, "We are now getting into the range of the wireless telegraphist." But, surely, one of the principal objects of the tramway or lighting electrical engineer is to keep as far as possible away from such a range of voltage and frequency, when dealing with dielectrics that would be sure to suffer from these effects. One of the chief difficulties which Mr. Marconi had to surmount, was to ascertain how best to arrange and proportion the values of his induction coils and condensers, that for a given primary power he might obtain the most effective electrical "splashes" across his "spark-gap." Both Marconi and his colleagues had made many calculations and experiments, and he understood that he required at Poldhu Station a steam engine of not less than 150 B.H.P. to generate his sending currents. This was, however, a mere nothing to the more powerful Pinkston engines; but happily their currents and circuits were not similarly directed and arranged, or we should have wireless waves sent right round the earth!

Mr. Hird. Mr. W. B. Hird said: The practical uses to which the oscillograph might be put have been strikingly brought out in this paper, and in this connection there was one point specially noticeable. Mr. Field mentioned that he was unable to obtain good curves when the conditions of the circuit were such as to produce resonance and give great amplitude of the harmonics he was observing, because the oscillograph motor under these conditions fell out of step. Some years ago he had worked with a very rough oscillograph; the curves were obtained by passing the currents to be observed through long wires stretched in a magnetic field, and carrying mirrors, the beam of light from which was thrown, not as in the present instrument on a vibrating, but on a rotating, mirror. The curve was thus drawn out in a long trace, and by working in a dark room a photograph could easily and simply be obtained on a sensitive plate or strip of bromide paper. As many of the phenomena which it would be most interesting to observe were obtained under conditions which were likely to throw the oscillograph motor out of step, it would appear that some such method of doing away with the synchronous motor would have some advantages. Whilst quite agreeing with Mr. Field that a 12th or any even harmonic is inadmissible in curves obtained from the generators he described, because it would make the positive and negative halves of the curves dissimilar, he saw no reason why such a machine should not produce current curves in which the right and left halves of each half-period were unsymmetrical, and he therefore did not see that the fact that an even harmonic would produce such want of symmetry could be quoted as an additional reason for the absence of such harmonics.

Mr. Field, after giving his very ingenious explanation of how the 11th and 13th harmonics in each of the three phases combine to give 12 ripples in the D.C. curve, said that no other pair would combine in the same way; it seemed, however, that the 5th and 7th harmonics, if present in each of the three phases, would combine to form 6 ripples, and the 17th and 19th to form 18 ripples, in exactly the same way, and using the same reasoning as that by which it is shown that the 11th and 13th combine to give 12 ripples. It would be extremely interesting to examine the D.C. curves, and to attempt to increase the amplitude of these harmonics, say, by resonance, so as to detect either 6 or 18 ripples in the curve; and if such were discovered, this would be a striking confirmation of Mr. Field's theory of the genesis of these ripples. Mr. Hird.

Mr. S. BLACKLEY said: After such a lengthy paper, it was very difficult to add anything further to try to satiate the desire for information on this interesting subject, as Mr. Field has suggested that he should do. Resonance was a most fascinating property of the electric circuit, and the importance of its effects on alternating-current systems was frequently under-estimated, if at all considered. It was usually stated that, in practice, the danger accruing from resonance was a myth, or that, no bad effects having resulted so far, the system under consideration was immune from danger of this kind. When they considered that the insulation of our electrical plant and cables must be deteriorating to a certain extent as time goes on, and remembered that in a high-tension system, consisting, say, of transformers, induction motors, and perhaps fifty or sixty miles of good capacity-giving cable, the resonating combinations which might occur are numerous, they should keep in mind the possibility of trouble from resonance effects. He should recommend any one who was inclined to be sceptical on this question to endeavour to obtain a glimpse of the effects (as shown by an oscillograph) which a resonating harmonic of even a moderate frequency had on the E.M.F. wave of an alternator on no load, or to watch the arc formed on opening a high-tension air-break switch in the circuit in which resonance existed. On switching on a few high-tension feeders he had seen the 13th harmonic in Curve XX. resonate to such an extent that all semblance to the original wave form had disappeared, and slightly undulated sinusoidal wave of great amplitude and of a periodicity of 325 cycles per second had taken its place. The question naturally occurred—What would happen if they had a small polyphase synchronous motor running light on this circuit when these cables were switched on? Would the motor, with its field not too strongly excited, prefer to stand still or to speed up to synchronism at the higher frequency? In either case, if they had no previous knowledge of what was going on in the circuit, he expected that the result would be attributed to the speed variation of the engine. Previous to Mr. Field's experiments he had frequently noticed, but could not account for, the sparking which was exhibited all over the high-tension feeder circuit-breakers in the sub-stations as the main engine was starting up in the morning or slowing down at night. This sparking seemed to be statical in nature, and occurred between the woodwork and iron fittings of the Mr. Blackley.

Mr. Blackley.

circuit-breakers. On investigation it was found that the phenomenon always appeared and disappeared at a certain voltage, lower than the normal, as indicated by the high-tension voltmeter in the sub-station, the needle of the instrument remaining stationary for a few seconds while the sparking lasted.* Immediately after the sparking had ceased the voltage began to rise gradually, and nothing further was noticed. They then examined the E.M.F. wave by means of the oscillograph as the voltage fell at night, and found that sparking commenced when the main engine reached a speed such that the frequency corresponding was of a value suitable to produce resonance of one of the harmonics in the wave. The wave form was very similar to that shown in Curve XV. From a consideration of the formula for resonance, viz., $1 = 4 \pi^2 n^2$ K L, the above result would be expected. Since adopting Mr. Field's suggestion as to starting up or shutting down on the high-tension side the sparking had disappeared, except at the normal voltage of 6,500, and only then when a certain length of cable was in circuit. On page 667 Mr. Field referred to the method of arriving at the capacity of the cables by measuring the charging current flowing into them. Perhaps it would be wise to explain that they only expected to arrive at an approximate value of the capacity by the method indicated. The inconsistency in the results was largely due to the fact that the E.M.F. wave of the alternator was not sufficiently near the sinusoid in form to admit of the use of the formula $C = 2 \pi n$ V $K/10^6$. The results served, however, to show how utterly unreliable this method of determination of capacity was even for approximations. It was well-known that the capacity current would be a minimum when the alternator used gave a pure sine wave. In a later test, which he had not had an opportunity to confirm, he measured the current flowing into the cables when the capacity was such as to give the conditions indicated by Curve XX. and again under conditions of more pronounced resonance than in Curve XV. Strangely enough, the results were only consistent if, in the former case, they calculated the capacity using 25 as the value of the frequency, while in the latter the frequency is taken as 13 by 25. The capacity values determined only vary by 3 per cent., the higher value going with the higher frequency.

Dr. J. B. Henderson.

Dr. J. B. HENDERSON said that Mr. Field assumed that the ripples on the alternator E.M.F. wave consisted of sine curves superposed on the fundamental. This might not represent the facts in every case, but it was an assumption as justifiable as that the E.M.F. curves of our old alternators were sine curves, and it might lead to some important general conclusions. Working on this assumption, he had calculated the harmonics, up to the 29th, which were present in the ripples shown in Figs. 7 and 8. Mr. Field had already calculated some of those present in Fig. 7, but it was Fig. 8 which represented the E.M.F. curve of each phase winding of the alternator. The ripples, however, which Mr. Field traced by means of the oscillograph were the ripples on the line E.M.F. curve, and as the alternator windings were connected in star,

* The voltmeter used was of a type which would not read correctly at all frequencies.

Dr. J. B. Henderson.

they were the ripples which resulted from combining two of the curves, like Fig. 8, at 60° phase difference. If we represented the amplitudes of the ripples in Fig. 8 by 1, 2, 2, 2, 2, 1, the amplitudes of the ripples in the resultant wave were 1, 3, 4, 4, 3, 1. It was interesting to notice that all harmonics which were multiples of 3 disappeared by a combination in star and were magnified by a combination in mesh, so that they would cause currents to circulate in the delta. The accompanying table gave the values of the harmonics up to the 29th in the three cases which he had mentioned. It would be noted from the last column that on the line wires the harmonics 11 and 13 were more than thirty times as important as any of the others, except, of course, the first, which synchronised with the fundamental, and was therefore of no account in our comparison. Professor Maclean was, he understood, analysing some of the actual oscillograms taken by Mr. Field. If his analysis did not agree with the last column it simply proved that the sine curve assumption was wrong for this particular alternator. In analysing these ripples he presumed that Professor Maclean had, first of all, corrected the curves for the errors of the oscillograph which Mr. Field mentioned in the paper, as the inequality in the horizontal scale of the oscillogram would introduce much more serious errors in the analysis for the higher harmonics than for the lower.

When we considered the combination of three similar line E.M.F.'s in mesh connection as in the rotary converter armature, the harmonics also combined at phase differences which depended on the particular harmonic considered. The phase difference in the n^{th} harmonic was $n \times 120°$. We found then that the harmonics 1, 7, 13, 19, 25, etc., combined at + 120° phase, while the harmonics 5, 11, 17, 23, etc., combined at − 120° phase. If therefore the fundamentals gave a rotating field in one direction, the harmonics 7, 13, 19, 25, etc., would give rotating fields in the same direction, and the fields due to the harmonics 5, 11, 17, 23 would rotate in the opposite direction. The speed of field rotation was, of course, proportional to the frequency. By reasoning similar to that used by Mr. Field for the 11th and 13th harmonics applied to the rotary converter, we saw that there would be ripples on the direct-current E.M.F. of the rotary having 6, 12, 18, 24, etc., waves per period of the alternating current. Since these were all even harmonics, the direct-current curve should always be a smooth curve, no matter how angular the E.M.F. curve on the alternating side might be with its odd harmonics. The D.C. Curves III., X., and XI. were a strong confirmation of the much greater intensity of the 11th and 13th harmonics than of any of the other harmonics in the A.C. E.M.F., and these curves therefore tended to confirm the figures given in column 14 of the above table. He had to thank Mr. Field for giving him the opportunity of discussing this excellent paper, in which he felt a great interest, as he had conversed with him from time to time about the work, and had been privileged to watch the actual changes taking place in the E.M.F. waves as the cable system was altered.

RELATIVE INTENSITIES OF HARMONICS IN E.M.F. CURVES OF ALTERNATORS WHICH HAVE 2 SLOTS PER POLE PER PHASE.

Harmonic Frequency when Fundamental Frequency is 1.	E.M.F. as represented in Fig. 7. Semi-amplitude of Ripples = b.	E.M.F. as represented in Fig. 8. Probable E.M.F. wave of each phase winding. Semi-amplitudes of Ripples = b, $2b$, $2b$, $2b$, $2b$, b.	E.M.F. on Cables, due to combination of two phase E.M.F.'s in star connection. Semi-amplitudes of Ripples = b, $3b$, $4b$, $4b$, $3b$, b.
1	$\frac{4b}{\pi} \times (1 - \frac{1}{26} + \frac{1}{22} = 1{\cdot}0069)$	$\frac{8b}{\pi} \times (\text{Sin}^2\, 75 \times 1{\cdot}0069 = 0{\cdot}939)$	$\frac{16b}{\pi} \times (\text{Sin}^2\, 75 \times \frac{\sqrt{3}}{2} \times 1{\cdot}007 = 0{\cdot}814)$
3	$\frac{1}{3} - \frac{1}{30} + \frac{1}{18} = 0{\cdot}3556$	$\text{Sin}^2\, 45 \times 0{\cdot}3556 = 0{\cdot}1778$	$0{\cdot}0$
5	$\frac{1}{5} - \frac{1}{34} + \frac{1}{14} = 0{\cdot}2420$	$\text{Sin}^2\, 15 \times 0{\cdot}2420 = 0{\cdot}0162$	$- \text{Sin}^2\, 15 \times \frac{\sqrt{3}}{2} \times 0{\cdot}242 = -0{\cdot}0140$
7	$\frac{1}{7} - \frac{1}{38} + \frac{1}{10} = 0{\cdot}2166$	$\text{Sin}^2\, 15 \times 0{\cdot}2166 = 0{\cdot}0145$	$- \text{Sin}^2\, 15 \times \frac{\sqrt{3}}{2} \times 0{\cdot}217 = -0{\cdot}0125$
9	$\frac{1}{9} - \frac{1}{42} + \frac{1}{6} = 0{\cdot}2540$	$\text{Sin}^2\, 45 \times 0{\cdot}2540 = 0{\cdot}1270$	
11	$\frac{1}{11} - \frac{1}{46} + \frac{1}{2} = 0{\cdot}5692$	$\text{Sin}^2\, 75 \times 0{\cdot}5692 = 0{\cdot}5308$	$+ \text{Sin}^2\, 75 \times \frac{\sqrt{3}}{2} \times 0{\cdot}569 = 0{\cdot}4596$
13	$\frac{1}{13} - \frac{1}{50} - \frac{1}{2} = -0{\cdot}4431$	$\text{Sin}^2\, 75 \times -0{\cdot}4431 = -0{\cdot}4133$	$- \text{Sin}^2\, 75 \times \frac{\sqrt{3}}{2} \times 0{\cdot}443 = -0{\cdot}3580$
15	$\frac{1}{15} - \frac{1}{54} - \frac{1}{6} = -0{\cdot}1186$	$\text{Sin}^2\, 45 \times -0{\cdot}1186 = -0{\cdot}0593$	
17	$\frac{1}{17} - \frac{1}{58} - \frac{1}{10} = -0{\cdot}0584$	$\text{Sin}^2\, 15 \times -0{\cdot}0584 = -0{\cdot}0039$	$+ \text{Sin}^2\, 15 \times \frac{\sqrt{3}}{2} \times 0{\cdot}058 = 0{\cdot}0034$
19	$\frac{1}{19} - \frac{1}{62} - \frac{1}{14} = -0{\cdot}0349$	$\text{Sin}^2\, 15 \times -0{\cdot}0349 = -0{\cdot}0023$	$+ \text{Sin}^2\, 15 \times \frac{\sqrt{3}}{2} \times 0{\cdot}035 = 0{\cdot}0020$
21	$\frac{1}{21} - \frac{1}{66} - \frac{1}{18} = -0{\cdot}0231$	$\text{Sin}^2\, 45 \times -0{\cdot}0331 = -0{\cdot}0115$	
23	$\frac{1}{23} - \frac{1}{70} - \frac{1}{22} = -0{\cdot}0162$	$\text{Sin}^2\, 75 \times -0{\cdot}0162 = -0{\cdot}0151$	$- \text{Sin}^2\, 75 \times \frac{\sqrt{3}}{2} \times 0{\cdot}016 = -0{\cdot}0130$
25	$\frac{1}{25} - \frac{1}{74} - \frac{1}{26} = -0{\cdot}0120$	$\text{Sin}^2\, 75 \times -0{\cdot}0120 = -0{\cdot}0111$	$+ \text{Sin}^2\, 75 \times \frac{\sqrt{3}}{2} \times 0{\cdot}012 = -0{\cdot}0097$
27	$\frac{1}{27} - \frac{1}{78} - \frac{1}{30} = -0{\cdot}0091$	$\text{Sin}^2\, 45 \times -0{\cdot}0091 = -0{\cdot}0046$	
29	$\frac{1}{29} - \frac{1}{82} - \frac{1}{34} = -0{\cdot}0071$	$\text{Sin}^2\, 15 \times -0{\cdot}0071 = -0{\cdot}0047$	$\text{Sin}^2\, 15 \times \frac{\sqrt{3}}{2} \times 0{\cdot}007 = 0{\cdot}0004$

Professor A. GRAY said that he had read Mr. Field's paper with much interest, and regarded it as an example of the benefit to be derived from a free use of Mr. Duddell's beautiful instrument. When once the curves had been thus drawn, the well-known methods of harmonic analysis could be at once applied to separate out the harmonics which existed in the wave forms, and thus to exhibit the fundamental components of the action of the machines. This was a further step of some importance, and perhaps some of the mechanical analysers which had been devised for periodic curves might be made use of in this connection. It was only by such registration of the behaviour of machines and subsequent analysis that we could obtain light upon the various matters which were still obscure in the action of generators of different kinds. He had felt specially interested in the discussion on resonance, and in that part of the paper dealing with the alternating charge and discharge of cables. The curves, though small in scale and therefore difficult to examine closely, were almost surprisingly identical with the curves that one could draw for the oscillatory subsidence of the charge of a condenser from the theoretical equation, obtained by supposing the plates connected by a coil of definite unvarying self-inductance. The crests of the successive ripples lay on the exponential curve (*e.g.*, Figs. 24, 26, etc., if it was that these had been drawn for actual cases by discharge through the inductive coils of a machine) which one would have expected in such a case. Now, the self-inductance of the circuit could not be constant in this case, but must be some function of the current, and therefore of the time; and the exact solution of the differential equation could not be given unless this function was known, and almost certainly only by approximation even then. He would like to see a large scale of curves for this case. In the meantime, it was interesting to have the results given in the paper. The fact that the potential on a cable at charge or at discharge might be very much greater than the working potential was, of course, a result that might have been anticipated without experiment, but Mr. Field's exhibition of it in this way must be of great value to practical men in calling attention to the matter, and in causing those in charge of plant of this description to realise the danger that probably had not occurred to anybody. Prof. Gray.

There were a good many corrections required in the proof, which would no doubt be made by the author, and he did not desire to make these in any way a matter of criticism. But some of the more mathematical slips should be carefully scrutinised. There were some points in connection with the curves which he had not yet had time to consider, which he should like to go into at some future time—for example, as to curves XXXVI., which were very interesting.

The only other remark he would make at present was as to the definition of self-inductance. There were two definitions current; one was the equation

$$E = R\,C + L\,\frac{d\,C}{d\,t}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

in which it denoted the coefficient of the time rate of variation of the current $d\,C/d\,t$ in the expression for the electromotive force in the

Prof. Gray. circuit. In a circuit containing iron, of course, L was not a constant, but was the rate of variation $d\,N/d\,C$ of the total number N of lines of force through the circuit with variation of the current C. This definition had, no doubt, its advantages for dynamo work, otherwise practical men would not employ it, and he was not to be taken as objecting to it. But there was the other sense in which the term self-inductance had been employed by most of the pioneers in electro-magnetic theory; the defining equation was here

$$N = L\,C \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where N had the same meaning as before, L was not here a constant either, and its relation to the L of the former equation was easily exhibited. We had clearly from the equation just written

$$\frac{d\,N}{d\,t} = l\,\epsilon\,\frac{d\,N}{d\,C}\,\frac{d\,C}{d\,t}$$

$$= \left(L + C\,\frac{d\,L}{d\,C}\right)\cdot\frac{d\,C}{d\,t}$$

by (2), so that if we denoted the L defined by equation (1), that is $d\,N/d\,C$ by L′, and use L for the quantity defined by equation (2), we had—

$$L' = L + C\,\frac{d\,L}{d\,C}.$$

The difference was that L′ united in one symbol the two parts of the coefficient of $d\,C/d\,t$ in the equation of electromotive force (1); and the two values coincided in the case of constant self-inductance. As he had indicated, there was this double use of the term self-inductance, which was, he thought, a pity. One definition was as directly applicable to alternating circuits as the other; the important thing to remember in either case was that when there was iron present the self-inductance was variable. The matter was entirely one of definition, and in that the convenience of all concerned should, of course, be consulted.

Perhaps it was unnecessary, but there was no warning given, so far as he could see, that the whole mathematical disquisition commencing on page 677 to near the end proceeded on the assumption that L was constant, which, of course, it was far from being in the circuits of the machines usually employed in the work referred to.

The paper represented a vast amount of good work, though in its present uncorrected form its complete perusal was a matter of considerable difficulty. He hoped that it would be printed, so that its results might be fully understood and appreciated.

The Three Hundred and Ninetieth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, March 12th, 1903—Mr. JAMES SWINBURNE, President, in the chair.

The minutes of the Ordinary General Meeting of February 26th, 1903, were, by permission of the Meeting, taken as read and signed by the President.

The names of new candidates for election into the Institution were also taken as read, and it was ordered that their names should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

From the class of Associate Members to that of Members—

Ralph Henry Covernton.

From the class of Associates to that of Associate Members—

Alfred S. L. Barnes	Andrew Stewart.
George Richard Drummond.	E. Taylor.
Richard Christopher Simpson.	H. Osborn Wraith.

Warwick Makinson.

From the class of Students to that of Associates—

Harold Thomas Brown.	Frederick Edward Kennard.

Cuthbert John Greene.

Messrs. Quin and Speight were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from the Italian Ambassador ; to the *Building Fund* from Messrs. R. C. Barker, J. R. Bedford, W. J. Bishop, R. H. Burnham, A. D. Constable, R. A. Dawbarn, F. W. E. Edgcumbe, W. Fennell, A. G. Hansard, E. R. Harvey, C. E. Hodgkin, G. F. R. Jacomb-Hood, Lord Kelvin, H. Kilgour, H. Lea, A. E. Levins, F. H. Nicholson, M. Robinson, H. Seward, F. W. Topping, C. E. Wigg, and A. P. Whitehead ; and to the *Benevolent Fund* from Messrs. W. J. Bishop, R. V. Boyle, M. S. Chambers, K. W. E. Edgcumbe, J. W. Fletcher, Prof. R. T. Glazebrook, E. P. Harvey, A. E. Levin, M. Robinson, A. P. Trotter, H. J. Wagg, and R. W. Weekes, to whom the thanks of the meeting were duly accorded.

The PRESIDENT: It will be within the knowledge of many of the members that the Council has been engaged for some time past in the preparation of Wiring Rules. A committee has sat and worked very hard in connection with the subject, and we have now drafted a set of Wiring Rules, which have been passed by the Council, having first been dealt with word by word by a very large and representative Committee. The Wiring Rules have been submitted to the Incorporated Municipal Electrical Association, which, after making some slight alterations and improvements, has adopted them. That body had a representative on the Committee. Several of the largest Fire Insurance Companies have also adopted the Rules. The Wiring Rules at present issued by different bodies are not only divergent, but in some cases incompatible with the new set of Rules as drawn up by this Institution. We hope that our Rules will gradually supersede others, and introduce uniformity in standardisation. It is proposed to send them to supply engineers, consulting engineers and the Power Companies and contractors, and it is hoped that members will use every possible effort to get the Rules adopted, and will use them themselves whenever they possibly can, and so gradually get them introduced universally. A Standing Committee has been appointed, so that if any alterations arise from time to time they can be dealt with as they arise. It will not be necessary to wait until there is any very large improvement needed. Any small alterations can be made practically at once if it is found necessary.

There is another matter which has been before the Council for some time to which I desire to draw attention, namely, that a Telegraph Conference is to be held in England in May or June of this year. Most of us in our days come to listen to papers in this Institution which are not Telegraph papers, but we must remember that Telegraphy was the original work of this Institution. We were originally a telegraph society, and although we do not now get so many papers and novelties on the subject of telegraph work, telegraphy is by no means correspondingly unimportant. In fact, it is the other way about; telegraphy has got to such a high pitch of perfection that there is very little to bring forward before the Society. Telegraphy is of enormous importance to this Institution. I may remind you that this Congress is an International affair, and will be a very large and important gathering; the Council therefore feels that we ought to do everything we can to entertain the Congress, and to take our proper part in the proceedings. But a difficulty at once occurs, because it will be held at the end of one session and the beginning of the next. The Council feels, and has felt all along, that the right thing to do is to have one President to take charge of the Institution over that time, and to have a President selected for that purpose. There is one man in particular who is exactly the right man to be President under those circumstances, and I have little doubt the Council will select him. In order that the Council may have the opportunity of selecting a President, and of his being elected so as to preside during the Congress, and to give him ample time to make the needful preparations, I propose to send in my own resignation between this and the

next meeting. Then, by the Regulations, the Council will be able to nominate their own new President, who will take charge on that election until the General Meeting. After the General Meeting, of course, the President has to be nominated and elected in the usual way by the Institution; but when you know whom the Council proposes as President I know you will be unanimous in electing him for the following year also.

I will now call on Mr. Fawssett to read the paper which he has written together with Mr. Constable. It is most unfortunate that Mr. Constable is very seriously ill. He was not able to be here on the last occasion, and he is not able to be here to-night, but we hope very much he will be able to be present at the next meeting, and give him our best sympathies.

DISTRIBUTION LOSSES IN ELECTRIC SUPPLY SYSTEMS.

By A. D. CONSTABLE, Associate-Member, and E. FAWSSETT, Associate.

"*Dare quam accipere.*" This is a motto not universally followed by electrical engineers in the course of their business, yet in the case of a particular supply-station of quite moderate capacity, over 800 tons of coal are annually given gratis to warm up the town, and the authorities, besides not receiving one penny towards the cost of it, do not even receive the thanks of the residents for the grateful warmth provided.

Few central-station engineers expect to get paid for more than 75 per cent. of the energy they generate. Of the remaining 25 per cent. about four-fifths is absolutely wasted; and worse than that, it increases the waste which would otherwise take place. The other fifth is used in the station itself for lighting and other purposes, and cannot be said to be actually wasted, although it is unproductive as regards revenue.

It is worth while considering how this wasted 20 per cent. is made up, and whether it is possible to reduce it in any way, since it costs as much to generate each unit wasted as each unit sold.

The figures given in this paper refer to the Croydon Electricity Works.

The total losses incurred between the generator terminals and the consumers' terminals, leaving out of consideration the units used in the station for field excitation, lighting and driving auxiliaries, may be subdivided under the following five headings:—

(1) Losses in Switchboards and Connections.
(2) Losses in High Pressure Feeders.
(3) Losses in Transformers.
(4) Losses in Low Pressure Cables.
(5) Losses in Meters.

These are discussed under the various headings, Nos. 2 and 4 being taken together.

SWITCHBOARD LOSSES.

Notwithstanding the fact that we are not dealing with a material substance like gas, which has to be conveyed through pipes with innumerable possibilities of leakage, there is an actual loss in transmitting electrical energy to the consumers of over 20 per cent. of the total energy sent out of the station.

The actual loss by leakage is extremely small; by far the larger part is, of course, due to our having no perfect conductors at our disposal, and this loss due to conductor resistance is infinitely more important than the corresponding loss of pressure due to pipe friction.

TABLE No. I.

LOSSES UP TO AND INCLUDING MAIN SWITCHBOARD.

	System of Supply.	Maximum Output.	Approximate Mean Loss in per cent. of Annual Output.
1	2,000 volts alt. cur. one pole earthed.	1,250 K.W.	0·43
2	500 volts direct cur. Tramways (A)	500 K.W.	0·42
3	500 volts direct cur. Tramways (B)	400 K.W.	0·30

Average loss in Substation Switchgear (System 1) and connections: 0·10 per cent. of output.

It becomes appreciable even at the feeder terminals on the main switchboard. Table I. gives these initial losses in the case of three different sets of plant. The values were obtained by measurement, and may be taken as a very fair average of the usual existing conditions. Careful arrangement of the relative positions of the switchboard and generators and simple design of the switchboard will, to some extent, eliminate these losses.

The minimum number of instruments should be installed, and these should be connected with as few joints as possible; ammeters should preferably be of the shunted type. Some switchboard erectors have a natural incapacity for screwing connections up tight, and some instrument makers are afraid of giving their customers too much metal; the authors have come across several cases of joints which have welded themselves together, of bus-bars running at or over 200° F., and even of switch-gear working at a temperature of 150° F. at normal full load.

One square foot of dull copper surface running at 10° F. above the temperature of the air will continuously dissipate the heat produced by

the absorption of about 16 watts, or, if the excess temperature is 50° F. the watts will be about 60.

Main fuses should be avoided where possible, not only because they are objectionable in themselves, but to be of use they must run warm and consequently waste energy.

It may be said that these are refinements beneath the notice of the practical engineer, but in the station under consideration, which is of fairly modern design with an output of only 1,250 k.w. at the maximum, the total loss per annum in the switch-gear and connections alone (including those in the substation) amount to 10,000 units, which, it will be readily granted, shows considerable room for improvement.

In those cases where the generator pressure is raised before transmission, in addition to the switchboard losses there are those in the step-up transformers to be taken into consideration; these are dealt with in the section on transformer losses later on.

Cable Losses.

Of all the losses in the system, the cable losses are the most important and those that can be least easily reduced. The larger part of this paper will, therefore, be devoted to their consideration.

The total losses in the cables may be split up into three components:—

(1) C^2R losses in the dielectric.
(2) C^2R losses in the conductor.
(3) Losses due to what may be called dielectric hysteresis.

The first may be shortly dismissed; it is, as stated above, generally very small, at any rate in the main feeders of a well laid out system.

The total insulation resistance between poles of this system of 2,000-volt feeders, comprising about 25 miles of concentric cable in nine separate feeders (ranging from ·15 □″ to ·025 □″) was 0·10 Ω, including switchboards at both ends. This, at a pressure of 2,000 volts, corresponds to a total leakage current of 0·02 ampere, or a loss of only 40 watts, or 350 units per annum, *i.e.*, 14 units per mile of high-tension cable.

The insulation of the low-tension network is, of course, very much less, and can, with difficulty, be measured; if we include all switchgear, network boxes, and services, it may be about 1,000 ω for 50 miles of cable, and at 200 volts the lost watts will be again 40, or 7 units per mile of cable per annum. The 50 miles of low-tension cable roughly correspond to the 25 miles of high-tension cable, so that the total leakage loss is only 700 units per annum.

The above figures give a rough idea of what may be expected in this direction, and it is useless to go into greater detail, owing to the enormous variations of insulation met with in practice. The insulation of a low-tension network may be of the order of ohms without being detected, for a long time. A case in a neighbouring system once came under the authors' notice in which there was a leak sufficient to raise a mass of concrete round a bunch of cables to a red heat before it was noticed; this is, happily, a very exceptional case.

The second cause of loss, viz., that due to C^2R in the cables, is of the greatest importance, and it also lends itself, in the case of feeders at least, to fairly accurate calculation. In the case of the low-tension network, however, the loss can only be approximately ascertained.

Table II. gives the C^2R losses for the whole of the Croydon system of mains. They have been worked out for each quarter of the year, the basis of the calculation being the load curves shown in Diagram No. I. The upper full curve is the load curve for a December week-day. The lower curve is the load for a day in July, and the middle curve is the mean for September and March. The curve for March is rather higher than that for September, owing no doubt to the latter being the holiday season. In working out the losses, these curves have been assumed to be the mean curves for the corresponding quarter, and the current in each separate feeder and distributor has been assumed to follow the same law as the total current.

TABLE No. II.

C^2R Losses in Cables.

Maximum Load Supplied: 1,250 K.W.

Description of Cables.	C^2R Loss in Units per Annum.
2,000 volt Feeders and Sub-feeders. About 25 miles, 0·15 sq. inch section to 0·025 sq. inch	47,200
400 and 200 volt Distributors. About 50 miles, 0·40 sq. inch section to 0·10 sq. inch	66,200
H.T. Arc Cables, 10·6 miles, 0·023 sq. inch Section (series)	11,400
L.T. Arc Cables. About 20 miles, 0·06 sq. inch and 0·025 sq. inch section	25,800
Total	150,600

This is, of course, not strictly accurate, but is near enough for the purpose of this calculation. An exception has been made in the case of the public lighting load, as this, of course, follows a different law. The lower dotted lines in the diagram are the load curves for public lighting, and are calculated from Diagram No. II. as a basis, there being in this case a total of 400 arc-lamps, 180 of which are switched off at about midnight. The greater part of these lamps are fed in parallel at 200 volts alternating, from low-tension mains used for no other purpose.

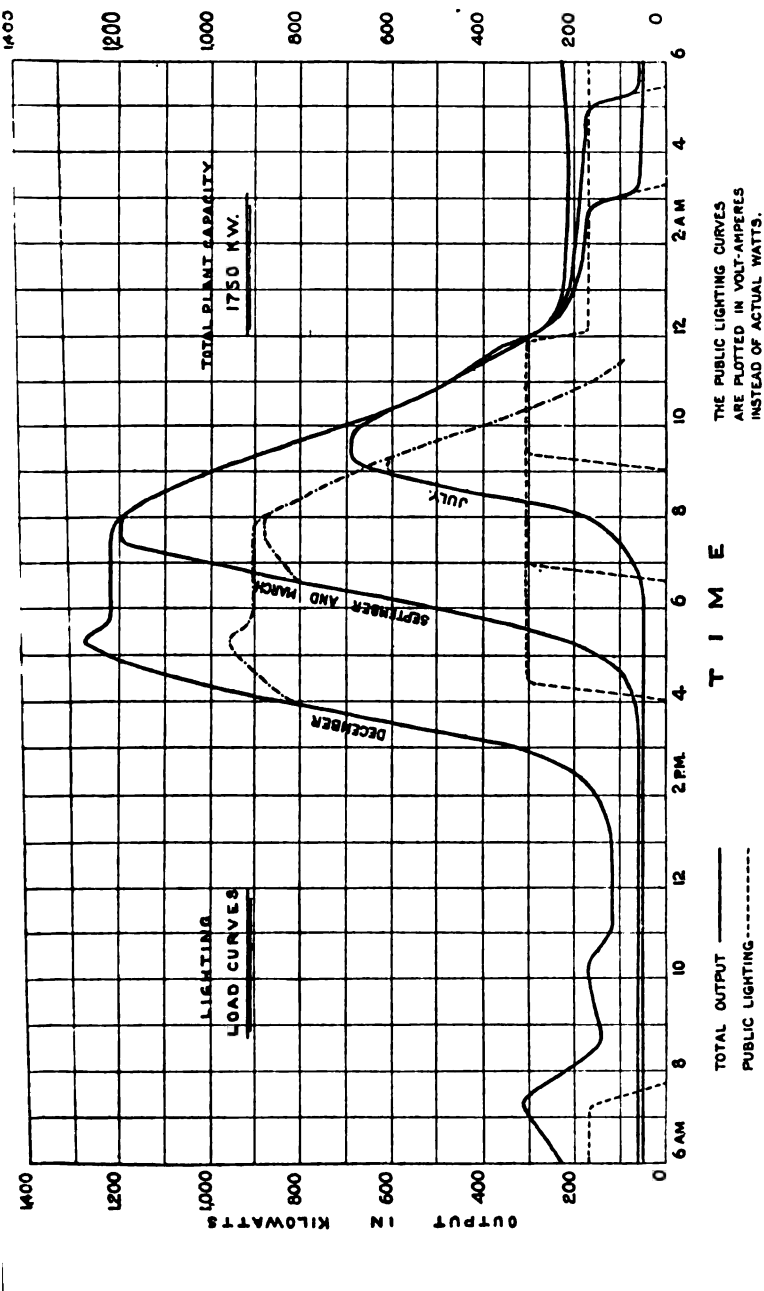

TOTAL PLANT CAPACITY
1750 KW.
LIGHTING
LOAD CURVES
DECEMBER
SEPTEMBER AND MARCH
JULY.
OUTPUT IN KILOWATTS
1400
1200
1000
800
600
400
200
0
6 AM
8
10
12
2 P.M.
4
6
8
10
12
2 AM
4
6
TIME
TOTAL OUTPUT
PUBLIC LIGHTING
PRIVATE LTG.
THE PUBLIC LIGHTING CURVES
ARE PLOTTED IN VOLT-AMPERES
INSTEAD OF ACTUAL WATTS.

DIAGRAM No. I.

These mains, however, take their supply from the same low-tension bus-bars in the substations as the private supply. There are in addition four high-tension series circuits supplying together 134 lamps.

The upper dotted curves are the private lighting load curves for the respective quarters, and are used to calculate the C^2R losses in the low-tension network, in conjunction with the observed average drop in potential between the substations and consumers' terminals, which latter averages four or five volts.

We now pass on to the third heading—"Losses due to dielectric hysteresis," to use the term for want of a better one. After the very thorough way in which this question was discussed recently before this Institution, perhaps an apology is needed for again bringing up the subject. As the question was not finally settled, it was the intention of the authors to experiment thoroughly on the large system of high-

HOURS OF PUBLIC LIGHTING

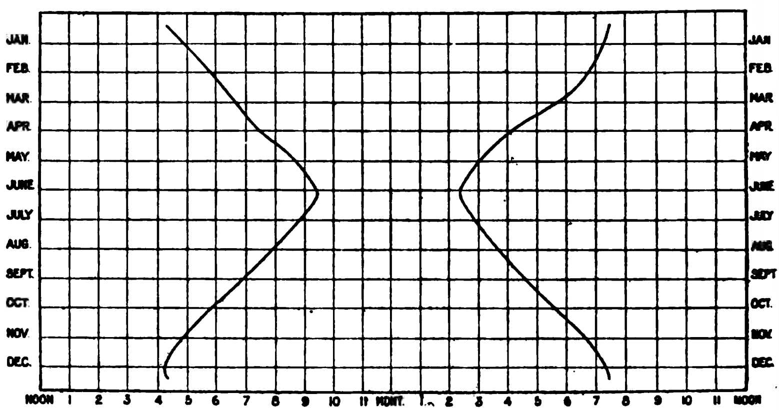


DIAGRAM No. II.

tension cables at Croydon, and find out once for all what the true losses incurred in actual working were; an additional incentive was the desire to again demonstrate that, contrary to the usual belief, it was possible in certain cases to obtain a power-factor as high as 0·10 in a cable, as was stated to be the case in Mr. Mordey's paper and in Mr. Minshall's contribution to the discussion thereon. The latter is conclusively proved by the figures in Table IV.

The more ambitious scheme was doomed to partial disappointment at any rate; it has been found a task of very great difficulty to obtain these losses with any reasonable accuracy with the instruments available in a fairly well equipped test-room. Numerous experiments have been made, but owing to the interruptions due to the necessary routine of work of a central station in an exceptionally busy year, these results are somewhat meagre and inconclusive. This section of the paper is, therefore, rather of the nature of a series of suggestions, and it is hoped that the discussion will produce further data.

The experiments are here discussed seriatim, as some of the methods adopted and the difficulties experienced, as well as the few results obtained, may be of interest.

The methods available for this investigation are :—

(1) Direct measurement of watts used in the cable by a wattmeter either with or without a choker to improve the power-factor of the circuit.

(2) Calculation of watts from plotted curves of volts and current or from oscillograph records.

(3) Direct measurement of increased power necessary to drive an alternator when a cable is switched on.

(4) Calorimetric method, *i.e.*, measurement of rise of temperature due to lost watts.

(5) Calculation of watts lost from known data and law of current variation determined experimentally.

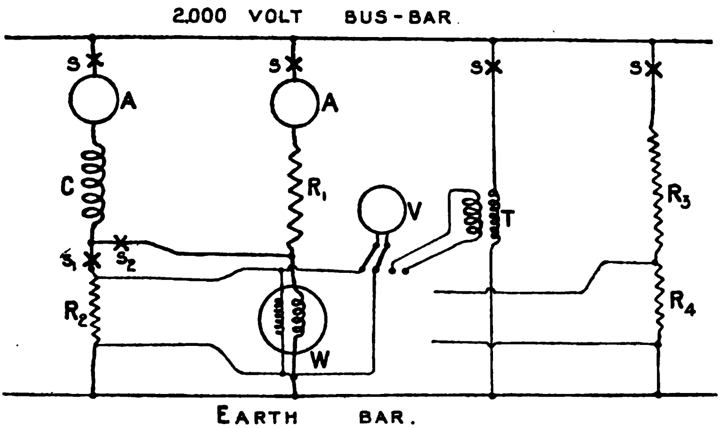


DIAGRAM No. III.

The first three methods have been used in this investigation with the results discussed below. Method (4) is one difficult of application and impossible in the case of cables in the ground, and is in any case open to many sources of error.

Method (5) has not been attempted, as sufficient data as to the law of current variation have not been obtained.

With regard to method (1), the first thing necessary was to discover what reliance could be placed on the readings of the ordinary commercial wattmeters at our disposal, when used on various power-factors.

Three wattmeters were used, viz. (1) a Swinburne with no unnecessary metal parts. This wattmeter had three different sets of current coils to give different sensibilities. (2) and (3) Thomson inclined coil wattmeters of different ranges with frames partly of metal. All three had large non-inductive resistances in series with the pressure coil, and were wound for 250 volts.

TABLE No. III.

Wattmeter Constants.

Date.	Nature of Load.	Power Factor.	Con-stant.	Scale Rdgs.	Voltage Curve similar to	Remarks.
			SWINBURNE WATTMETER.			
17-7-01	Non-Inductive Lamp Bank	1·00	9·92	15	No. 10 Sheet A.	Original Fine Wire Current Coil, about No. 16 S.W.G.
"	do. ..	1·00	10·05	21		
"	do. ..	1·00	9·83	30		
"	do. ..	1·00	9·90	56		
"	do. ..	1·00	9·88	80		
4-8-01	do. ..	1·00	9·93	14	12, St. B.	
6-8-01	do. ..	1·00	9·96	15	No. 10 Sheet A.	
"	do. ..	1·00	10·01	23		
17-8-01	do. ..	1·00	9·93	39		
6-8-01	Inductive, Current leading ..	0·129	9·03	2·5	No. 10 Sheet A.	
"	do. ..	0·374	9·98	61		
17-8-01	do. ..	0·141	10·20	5		
"	do. ..	0·143	10·17	3		
4-8-01	Do., Cur. lagging ..	0·032	9·74	2	No. 12 Sheet B.	
"	do. ..	0·304	9·38	16		
6-8-01	do. ..	0·034	10·26	2·5	No. 10 Sheet A.	
17-8-01	do. ..	0·035	10·90	2·5		
8-9-01	Do., Cur. leading ..	0·129	1·262	14		Current Coil re-wound with fine wire, about No. 26. S.W.G.
"	do. ..	0·129	1·195	30	No. 10 Sheet A.	
"	do. ..	0·142	1·256	25		
"	do. ..	0·142	1·193	45		
"	Do., Cur. lagging ..	0·034	0·952	25		
"	Do., Cur. leading ..	0·138	1·189	35	12, St. B.	
10-9-01	Non-inductive lamp bank	1·000	1·278	70–90	10, St. A.	Cur. Coil rewound as above, and also new volt coil.
	THOMSON WATTMETER 1 AMP. RANGE.					
4-8-01	Non-Inductive Lamp Bank	1·00	1·027	140	No. 12 Sheet B.	As used in all experiments after 4-8-01.
7-8-01	do. ..	1·00	1·00	60–140		
6-9-01	do. ..	1·00	1·063	140	No. 10 Sheet A.	
"	Induc-Cur. leading ..	0·141	1·016	30		
"	do. ..	0·141	1·040	50		
4-8-01	Do., Cur. lagging ..	0·032	1·271	13	No. 12 Sheet B.	
"	do. ..	0·304	1·026	150		
6-9-01	do. ..	0·035	1·015	22	10, St. A.	
	THOMSON WATTMETER, 10 AMP. RANGE.					
6-9-01	Non-inductive Lamp Bank	1·00	9·78	21	No. 10. Sheet A.	Not used owing to variable constant.
"	do. ..	1·00	9·96	37		
"	Inductive, Current leading ..	0·142	6·60	3·5		
"	do. ..	0·143	7·81	6		
17-8-01	Do., Cur. lagging ..	0·035	8·83	3		

The voltage was reduced in the ratio of about 10 : 1 by means of a bank of lamps, the actual ratio being measured for each set of readings; the voltage on the wattmeter was measured on a standard electrostatic instrument, and the full voltage was reduced by a transformer of known ratio and measured on the same voltmeter.

Diagram No. III. shows the connections for calibrating the wattmeters initially; it is almost self-explanatory, and power-factors of about 0·03 and 0·35 with current lagging, 0·14 with current leading, and unity were used in the calibration. The leading current was

obtained by passing a current through the series coil of the wattmeter in phase with the applied volts and connecting the pressure coil to a non-inductive resistance in series with a choker. The wattmeter is shown connected in this way in the diagram.

The power-factor of the ironless choker circuit of course can be calculated with very fair accuracy. The choker, as used throughout, consisted of 112 lbs. of No. 16 copper wire wound on a wooden drum. A thermometer was embedded in the winding and the temperature was taken for each reading.

The resistance, in series with the choker, consisted of lamps. It has been assumed throughout that the lamp banks used were non-inductive, no difference in phase between current and applied volts being observable on the oscillograph used in these experiments.

Table III. gives the constants obtained for the wattmeters under the various conditions.

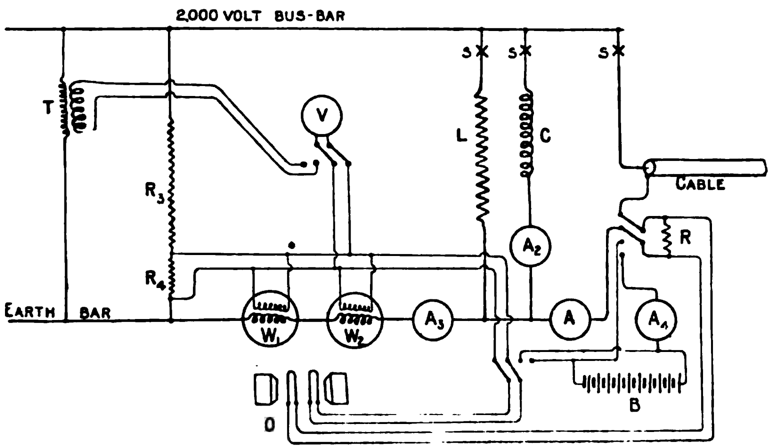


DIAGRAM No. IV.

It will be noticed that the Swinburne Wattmeter and the small range Thomson Wattmeter give fairly consistent results, although there are considerable variations with the different power-factors, chiefly due, in all probability, to the various wave-forms of the applied voltage. There are also variations in the constant obtained under the same conditions at different times, but as the constant used in working out the cable watts was that obtained under the most nearly corresponding conditions, and at the same time in most cases, the errors should not be large. Very low power-factors with leading current were not obtainable for calibration owing to the lack of a larger choker.

In the case of the larger range Thomson instrument the constants vary from 6·6 to nearly 10·0, notwithstanding the maker's statement that the instrument is correct for all power-factors and all wave-forms; this apparently applies between certain limits only. The readings of this instrument were, therefore, rejected. In the later experiments by

a slight modification of the connections it was possible to calibrate the wattmeter in use, on a load with leading current, for every reading, and this was done in each case.

The actual connections used in the cable experiments are shown in Diagram No. IV., two wattmeters being generally used in series as a check.

Readings were taken, both with and without the choker C in parallel with the cable.

L in the diagram is a bank of lamps, used in the earlier experiments in calibrating the wattmeters with PF = 1. The ammeters were all compared with a low-reading Siemens Dynamometer, but the final standard was an Elliott's Voltmeter, used in conjunction with a standard ohm.

The arrangement on the right of the diagram at the bottom is for the purpose of calibrating the oscillograph. A voltage of 130 D.C. could be applied to the oscillograph without altering the connections and the value of the deflection in volts thus obtained.

In the same way a known direct current could be passed through the non-inductive current shunt R, and the value of the oscillograph deflection in amperes ascertained.

The principal results obtained are given in Table IV., and the agreement of the watts absorbed in the cable as measured by the wattmeters and by working out the oscillograph curve, is in some cases good. These curves were worked out by taking the mean value of the instantaneous watts for 22, and in some cases 44, equi-distant points of time in the diagram of one complete period.

In several instances it will be noticed that the R.M.S. value of the voltage obtained from the oscillograph diagrams is higher than that measured on the voltmeter. This is probably due to the fact that the calibration was made with 130 volts instead of 200 volts, and the resistance of the lamps in series with the voltage strip was higher than it was in the actual experiment, thus making the oscillograph appear less sensitive than it really was.

In the case of Experiment No. 15 and onwards this possible error did not occur, as there were no lamps in series with the voltage strip, and the agreement is better, though in this case the voltage as measured is slightly higher than that obtained by working out the curves.

The watts taken by the choker alone have been also worked out from the oscillograph curves (Curves D), and the agreement with the calculated watts is in this case good.

Some experiments had to be made without the oscillograph, owing to its being out of order, so that in these cases the watts are only those obtained on the wattmeter. Some were made without a wattmeter and some without independently calibrating the oscillograph (see last column in Table IV.). In the four cases in which watts have been obtained, both from the oscillograph records and with a wattmeter, the two values are of the same order, but they do not agree as well as could be wished.

This is, no doubt, explained partly by the shape of the waves. In curves of shapes E, F, and G, for example, owing to the almost vertical-

Exp. No.	Date of Experiment.	Cable No.	Description.	Length. Yards.
1	21-7-01	4	Conc. jute insulated, lead-sheathed, armoured, direct in ground	2,100
2	8-9-01	4		
3	8-9-01	4		
4	14-7-01	7	Conc. V.B. insulated, laid solid in iron trough with iron cover, designed for 5,000 volts, worked at 2,000 volts	7,290
5	21-7-01	7		
6	4-8-01	7		
7	21-7-01	7		
8	4-8-01	7		
9	4-8-01	9	Conc. jute insulated, V.B. sheathed, laid solid in wood trough with No. 10	2,440
10	8-9-01	9		
11	8-9-01	9		
12	8-9-01	10	Conc. paper ins. V.B.S., laid solid in iron trough with tile cover, W.P. 5,000 v.	2,400
13	8-9-01	10		
14	4-8-01	Choking Coil	112 lb. No. 16 S.W.G., copper; wound without iron	—
15	-10-02	11	Concent. paper insulation V.B.S., laid solid in iron trough with tile cover, working pressure 5,000 volts	6,340
16	-10-02	11		
17	-10-02	11		
18	-7-02	11		
19	-7-02	11		
20	-7-02	11		
21	-10-02	12	See Note (i.) at foot	21,660
—	—	—	—	—

NOTES:—(i.) Cable No. 12 consisted of Cables Nos. 9, 13
type as No. 10.
(ii.) Worked out result of Curves E, F, and G pı
(iii.) Thomson wattmeter used in series with Swiı
(iv.) No wattmeter used in Experiments 15 to 21.
(v.) The Swinburne wattmeter with original fine
Nos. 2, 3, 10, 11, 12, 13.

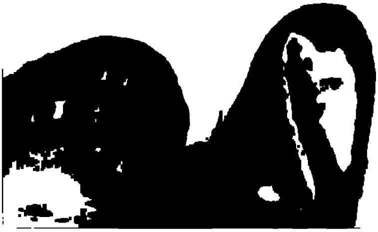
BLES.

. by and ter.	Watts by Wattmeter	Watts by Oscillograph.	Power Factor by Wattmeter	Power Factor by Oscillograph.	Corresponding Curves.	Remarks.
74	30	—	0·020	—	Applied volts as Curve 12, Sheet B	Ironless choker in parallel
10	49	—	·029	—		Cable alone
520	25	—	·017	—		Choker in parallel
520	635	—	·098	—	Current wave not taken	" " "
530	830	—	·112	—		" " "
,890	866	610	·126	0·090	B	" " "
,600	854	—	·112	—	As Exp. 5	Cable alone
,110	923	83[illegible]	·130	·110	A	" "
2,205	58	7[illegible]	·023	·033	C	" "
2,230	66	—	·030	—	Applied volts as Curve 12, Sheet B	" "
2,090	53	—	·025	—		Choker in parallel
1,535	112	—	·073	—		Cable alone
1,380	33	—	·024	—		Choker in parallel
5,560	Calc. 178	1[illegible]	Calc. ·032	·0315	D	Ironless choker, no cable
18,740	—	[illegible]	—	·0127	E	Oscillograph voltage strip only calibrated. Watts worked out from curves and the measured R.M.S. values of voltage and current. For I, J, and K neither strip was calibrated
13,530	—	[illegible]	—	·0175	F	
1,920	—	[illegible]	—	·0106	G	
25,650	—	2[illegible]	—	·083	I	
12,000	—		—	·080	J	
3,970	—		—	·078	K	
12,160	—		—	·074	L	
—	—		—	—	H	Sine curves equivalent to E

all. No. 14 = 1,650 ya same type as No. 9, and No. 13 = 1,640 yards of same

e with Swinburne, wit num variation of 10 per cent.

8, and 9. It was us coil rewound with No. 26 S.W.G. wire in Experiments



peaks, it is impossible to work out the watts even with approxi- accuracy. A horizontal difference of ·01 inch in the relative on of one of the peaks of the curves of current and volts will y alter the power-factor indicated.

it had been possible to obtain photographic records some im- ement in accuracy would have resulted, but as it is, with curves d by hand, very little reliance can be placed on the worked out er-factor of the very peaked waves.

On the other hand, simpler wave-forms can be worked out fairly rately; Curve D for example. Referring again to the table, it be noticed that very great discrepancies occur between various of readings on the same cable and also between the results ained with the choker in parallel with the cable and without it. e former results should be the more accurate, owing to the higher wer-factor.

Such figures are not very conclusive, but they have been obtained th all proper precautions, and it is hoped that some explanations of e discrepancies may be suggested.

Part of the differences may be due to the effect of alteration wave-form (1) on the actual losses, and (2) on the instrument dications.

It has not been definitely proved whether the power-factor of a able is altered by alteration of the wave-form of the applied voltage, r not. On the whole, it may be inferred that it is altered to some xtent, but not largely. With wave-forms as in curves E, F and G, the power-factor for a long paper-insulated cable comes out at about 0·014 averaging the three, and with curves H, I and J for the same cable and approximately the same voltage it is 0·08. A wattmeter was not used in this case.

This enormous difference cannot be put down wholly to the difference of wave-form, but is most probably due to the inaccuracy in working out the very peaked waves of the first set of curves, and the agreement of the three is probably more coincidence than anything else. The value obtained from the last three curves has been taken as the more probably correct.

With regard to the effect of wave-form on the other instruments used, it is stated by Benischke that there may be a difference of 10 per cent. in the readings of electromagnetic instruments with flat and peaked waves.

In calibrating the various instruments used, differences amounting to about 5 per cent. were found when using different wave-forms, the sub-standard being a Siemens Dynamometer with practically no metal parts in the frame, and this should read sensibly the same for different wave-forms and frequencies. The Thomson Ammeters read higher on the smoother waves. In working out the experiments the calibration with the particular wave-form of the experiment was that used. In Table III., giving the wattmeter constants obtained at different times, the form of wave is noted for each set of readings.

It was found that the voltage across the terminals of the current coil of the Swinburne Wattmeter (using the fine wire coil) varied in the

ratio of about 1 : 3 in the various experiments owing to the difference in the current frequency.

It is difficult to say to what extent a wattmeter may be relied on when the current has about double the frequency of the applied voltage.

In order to overcome the difficulty of very small scale readings on the wattmeters, the current coils were in most cases heavily overrun, a short-circuiting switch being put in except when taking readings.

It is interesting to note that in one experiment, not recorded in the table, the wattmeter gave a higher reading when short-circuited than when the current coil was in circuit, no doubt due to currents induced by the voltage coil, which was in circuit.

In all the recorded experiments the measuring instruments were placed in the earthed outer of the cables, as it was found that the readings were practically identical with those obtained with the instruments on the inner, and the safety of the arrangement was much greater.

It was considered a matter of interest to find out how the wave-forms and values of current and voltage, varied at different points in the length of a cable, if at all. An experiment was, therefore, made as follows:—

Six long cables were joined in series, and readings of current and voltage and tracings of the wave-forms were taken at each end and at the junction of the two middle cables. Four ends being accessible at the power-station, it was not necessary to move the oscillograph at all.

The readings taken at the end at which the voltage was applied are recorded in Experiment No. 12, Table IV., as are also the lengths and sections of the various cables.

The results of this particular test showed that, contrary to the authors' expectations, there was no observable difference, either in the voltage, or in the wave-forms of the voltage and current at the three points. The middle point was at the junction of Cables Nos. 10 and 11.

The current, of course, had different values at the three points, but whether it and the watts were in proportion to the equivalent length of cable cannot be stated with certainty, as the cables are of different types and sizes; the main point, however, is that there is no change in the voltage at the ends of the cable or in the shapes and relative phases of the voltage and current waves.

This experiment was made under different conditions: (1) with the cable open-circuited at the far end, and (2) with a small non-inductive load at the end. The results were the same in both cases except for a very slight reduction in the "kinks" in the voltage curves in the latter case and a slight shifting of the current wave owing to the higher power-factor.

The result is the more remarkable as it is the generally accepted view that in all long cables there is a rise of pressure due to the capacity; and, under certain conditions, this does undoubtedly take place. In all probability a variation of frequency would have produced the result expected.

YORK
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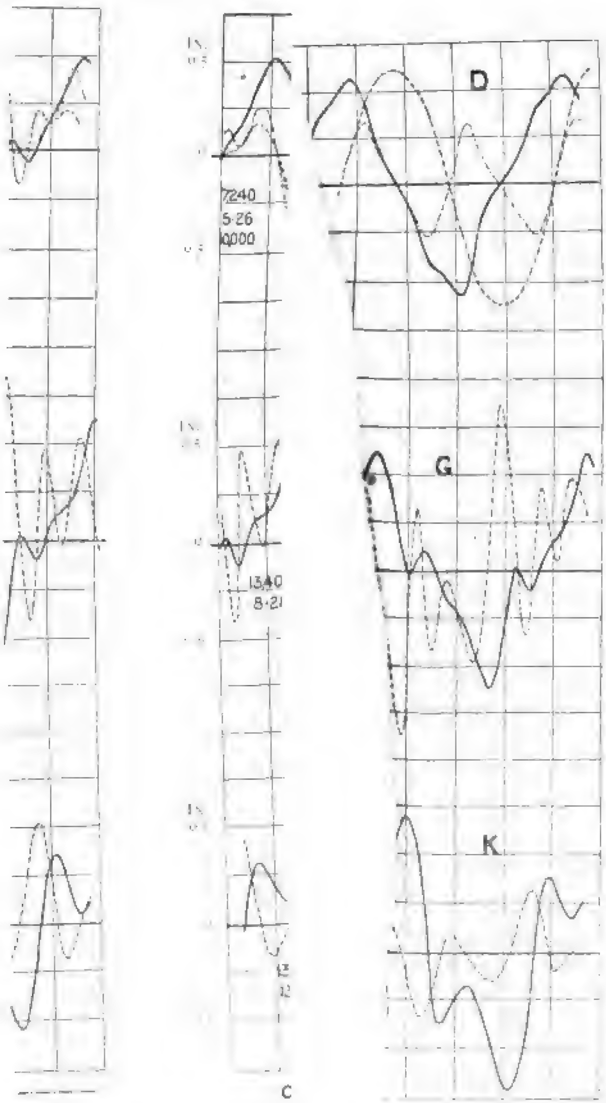
DATIONS.

. FORMS IN CABLES.

(SEE TABLE IV.)



... values per inch of vert...

It is unnecessary to show the curves obtained at the three points, as they are all practically alike.

The actual readings obtained are given in Table No. IV A.

TABLE No. IV A.

VARIATION OF CURRENT AND VOLTS ALONG CABLE.

		Volts.	Current.	Volt Amperes.	Watts by Oscillograph.
Cable on open Circuit.	Point A (near end)	2,000	6·08	12,160	901
	Point B (middle)	2,000	3·97	7,940	—
	Point C (far end)	2,000	0	0	0
Small load at end.	Point A	2,000	5·65	11,300	—
	Point B	2,000	3·75	7,500	—
	Point C	2,000	0·64	1,280	—

A wattmeter was not used in this experiment, and the oscillograph curves for the first reading only have been worked out.

The current and voltage curves in the last case are identical.

In addition to the above experiments, it was sought to confirm the results by the motor alternator method. The connections of the D.C. motor were as shown in Diagram No. V., the current being measured

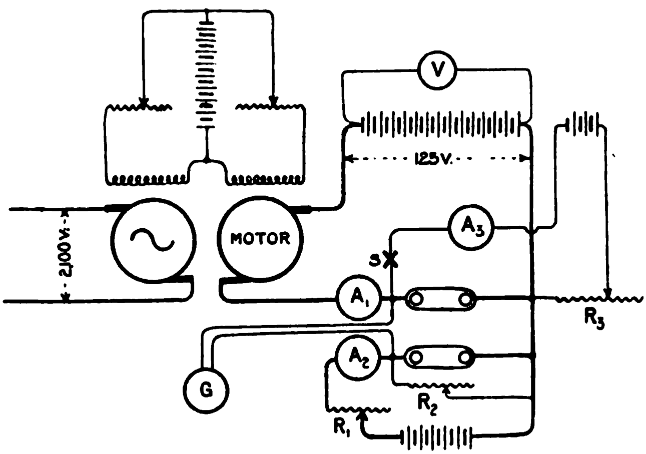


DIAGRAM No. V.

by a very sensitive differential method, which is clearly shown in the diagram. The galvanometer was calibrated by adding a small known current to the motor current and noting the scale deflection ; the scale was a proportional one.

Whilst this method was applicable to the V.B. cable, giving the watts

taken by the cable rather lower than the result obtained by the other methods, it was found that when the jute cables were switched on less current was taken by the motor than before, no doubt owing to the efficiency of the alternator being improved by the alteration in wave-form. This does not include the increase of efficiency due to the reduced exciting current, as the exciting current was separately measured.

This objection could probably be got over by adding an inductive load at the same time as the cable, and adjusting it until the wave-form of the alternator was of equivalent shape. This could be proved by either taking oscillograph waves of the potential, or preferably by connecting up a condenser (another cable might be used for the purpose) and adjusting the inductive load until the current flowing into the condenser was the same as without the cable under test. The inductive load would be produced by an air core choker, and could be calculated and deducted from the total increase in power taken by the motor. Owing to lack of time, no definite results were obtained by this method. The motor alternator experiments are of value, however, in showing the great difference between the V.B. cable and the others.

The improvement in efficiency, apart from the reduction in exciting energy, caused by connecting circuits having capacity is a factor to be reckoned with when condemning the wastefulness of high-pressure cables.

TABLE No. V.

Effect of Capacity on Exciting Current.

	Voltage on Cable.	Exciting Current without Cable.	Exciting Current with Cable.	Watts saved in Excitation.	Approx. Watts in Cable (Paper)
A	10,000	5·8	2·5	426	2,000
	5,000	5·8	4·7	142	500
	2,000	5·8	5·4	52	80
B	10,000	17·5	13·2	555	2,000
	5,000	17·5	16·0	193	500
	2,000	17·5	17·2	39	80

A—30 K.W. Alternator. B—120 K.W. Alternator.

Note:—In addition, there is a further improvement in the efficiency of the Alternator, due to the effect of the altered wave form on the armature losses.

Table No. V. gives the reduction in excitation energy in various cases, and it will be noticed that the saving is quite comparable with the loss by dielectric hysteresis; so that beyond the objection to running a larger generator than is required to supply the actual watts consumed, there is really no great loss due to the use of high-tension cables, at any rate at 2,000 volts. In the summary, however, dielectric

hysteresis losses are included, as exciting energy is not considered in this paper.

The effect of variation of voltage is shown in experiments No. 15–20. It will be seen that with the particular form of wave applied the current increases rather more rapidly than the voltage, and the watts rather more rapidly than the voltage squared. This, of course, means that with very high voltages the watts absorbed may be a formidable quantity; but at the same time it must be remembered that as the voltage increases, so does the thickness of the dielectric. The capacity is therefore less, and, assuming no resonance, the cable volt-amperes and the watts absorbed will by no means increase as the voltage squared.

Some experiments were made on the effect of frequency, and the power-factor does not seem to be largely altered. As, however, there was some doubt as to the accuracy of the instruments employed in these tests, the figures are not here recorded.

The effect of load on the cable on this loss has not been satisfactorily investigated. It implies taking the difference of two very large quantities, compared with the loss, and is therefore not susceptible of much accuracy. In any case, the time during which the feeders in a lighting station are loaded is so small a fraction of the whole time they are running that the difference in the total result cannot be large.

Taking a comprehensive view of the above results, there appears to be no doubt that in the case of the V.B. insulated cable, No. 7, the power-factor is of the order of 0·12, that of the jute-insulated cables about 0·025, and of the paper-insulated cables something of the order of 0·032 and 0·08 respectively for Nos. 10 and 11; the first three results are fairly consistent with all the statements made in the discussion on Mr. Mordey's paper. The V.B. cable appears to be an exceptionally bad cable from this point of view, and the 5,000-volt paper cables appear to have a larger dielectric hysteresis loss than the jute cables.[1]

It is noteworthy that the cable which shows an abnormally high power-factor, viz., No. 7, is laid in an iron trough with iron cover.

It is possible that this iron trough, completely surrounding the cable, accounts to some extent for the high power-factor.

Where the cable is in an iron trough with a tile cover, as in the case of Nos. 10 and 11, the power-factor is also higher than would be expected from the type of cable. All the cables in Exp. 12 have the outers of slightly larger sectional area than the inners—roughly, 5 per cent. to 10 per cent. larger.

The fact that an external field exists round these cables is proved by the humming noise produced in the telephones connected to pilot wires

[1] The thickness of the dielectric between conductors of cables No. 7, 10, 11, and 13 is 0·28 in. The thickness over the outer is 0·10 in., except for No. 7, in which it is 0·25 in.

The iron trough in which the cables are laid is approximately 3½ in. by 3½ in. outside and ¼ in. thick.

Cable No. 4 is armoured with steel tape, but the thickness is only about $\frac{1}{32}$ in., and the outer and inner conductors are of the same section.

The capacity of the V.B. insulated cable is abnormally high, being over hree times that of a similar paper cable.

laid parallel and close to the cables. That this noise is not due to leakage entirely is shown by the fact that it is slight during times of no load, and very loud at times of heavy loads. Public telephone cables along the same route, but further away from the lighting cables, are not appreciably affected.

Taking the values given above, the total hysteresis loss in the Croydon system of mains comes out at about 17,000 units per annum, and is approximately equally divided between the four quarters. This is not so large a loss that it is worth while shutting down feeders for the period of light load to reduce it considering the risks involved in so doing. It is most important, however, to decide on a dielectric which will not give an abnormal loss, as in the case of Cable No. 7.

Transformer Losses.

The next point to be considered—and it is one of more importance than losses in the cable dielectrics—is that of transformer losses in an alternating current supply.

TABLE No. VI.

Transformer Losses.

Maximum Load supplied	1,250 k.w.
Maximum Tranformer k.w. in use	1,790
Minimum Transformer k.w. in use	920

(a) Total losses during time of heavy load	88,800	units per ann.
(b) Total losses during time of light load...	31,200	do.
(c) Total loss during day load	53,200	do.
Total losses per annum ...	173,200	units.

Note:	June Quarter.	September and March Quarters.	December Quarter.
Period (a) is as follows	8 p.m. to 12 midnight.	5 p.m. to 12 midnight.	2.30 p.m. to 12 midnight.
„ (b) „	12 midnight to 3 a.m.	12 midnight to 5 a.m.	12 midnight to 2.30 p.m.
„ (c) „	3 a.m. to 8 p.m.	5 a.m. to 5 p.m.	—

Table VI. gives the annual losses in the transformers necessary to deal with 1,250 k.w. output at the Croydon station. These transformers are placed in 26 sub-stations scattered over the district, and the total number of 56 of 1,790 k.w. total capacity is made up of :—

2 — 100 k.w.
19 — 50 k.w.
26 — 20 k.w.
3 — 27 k.w.
6 smaller sizes.

These are all in use at times of full load, and the number does not include spares. The loss is cut down as far as possible by switching off transformers not required for load. An attendant frequently visits the sub-stations for this purpose.

Notwithstanding this method of securing economical working, the aggregate losses are very large.

If all the transformers were kept on continually, the additional core losses would amount to 40,000 units at least per annum.

As an attendant must in any case visit the sub-stations, the saving by this method of working is very considerable.

The losses given in the table are as nearly as possible the average losses in ordinary working. The core loss in a particular 100 k.w. transformer, however, was 979 watts as minimum, with an applied voltage wave as shown on Curve No. 19, Sheet B, and 1,078 watts as maximum, with a wave as shown on Curve No. 8, Sheet C.

As this difference is so considerable, it was of interest to investigate the variations of wave-form occurring in ordinary working throughout the twenty-four hours. The results obtained are most striking, and very different to what were expected.

The curves obtained serve to emphasise what is often not fully realised, namely, that the wave-form obtained from any given alternator is almost as largely dependent on the kind of load it is called upon to carry as upon the design of the alternator. The curves were traced on a Duddell's oscillograph, and the main connections made to obtain them were as shown in Diagram No. VI., and were such as not to alter the normal running conditions to any appreciable extent.

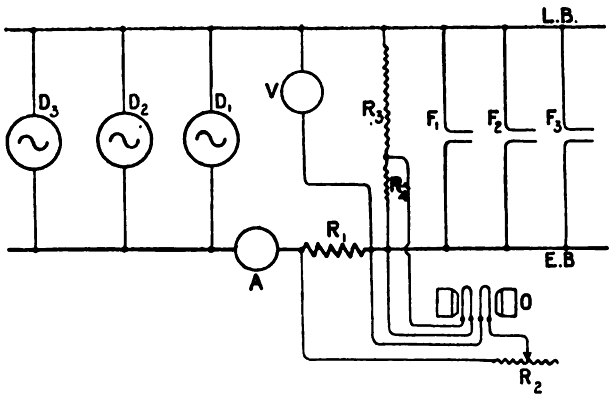


DIAGRAM NO VI.

LB is the live bus-bar and EB the earthed bar, the system of supply being 2,000 volts with one pole earthed. D1, D2, D3 are the alternators; F1, F2, F3 are the feeders; R1 is a non-inductive shunt carrying the whole current, and R3 and R4 are non-inductive resistances used as a potential divider to reduce the voltage from 2,000 across the bus-bars to the necessary 2 volts on the oscillograph; it consisted of a bank of

lamps with a small non-inductive resistance, R4 in series with it, across which the oscillograph voltage strip was connected; R1 consisted of brass condenser tubes arranged non-inductively, and tested for absence of self-induction. The height of the current waves was adjusted by altering the value of the shunt, and also by means of an adjustable resistance R2, in series with the oscillograph current coil.

The curves are sensibly correct in shape, but there may be slight errors due to their having been twice traced. There is also noticeable a slight difference in the horizontal width of the two half periods, due, no doubt, to a slight want of uniformity in the rotation of the mirror of the instrument. This error can, however, be allowed for.

TABLE No. VII.

Variation of Wave Form during 24 Hours.

No. of Curve, Sheet A.	Time.	R.M.S. Values.		Machines Running.	Remarks.
		Bus-bar Volts.	Total amperes		
	P.M.				
1	3.40	2,090	58	5	Transformers all on.
3	4.10	2,090	90	5, 7	
3	4.15	2,090	110	5, 7	
4	4.30	2,090	210	4, 5, 7	
5	4.45	2,100	350	1, 4, 5, 7	Some arcs on.
6	5.5	2,100	505	1, 2, 4, 5, 7	All arcs on (150 amps. for arcs.)
7	5.40	2,110	534	1, 2, 3, 4, 5, 7	
8	6.50	2,110	558	1, 2, 3, 4, 5, 7	Maximum load.
9	9.5	2,100	340	4, 5, 7	
10	9.15	2,100	310	5, 7	Some transformers off.
11	11.5	2,100	215	5, 7	
12	11.35	2,100	170	7	
	A.M.				
13	12.30	2,080	124	3, 4	H.N. arcs off.
14	2.10	2,070	118	3, 4	1 Transformer in each Substation on only.
15	4.50	2,070	103	3, 4	
16	6.3	2,070	114	3, 4	
17	7.15	2,070	130	3, 4	Some A.N. arcs. off.
18	8.4	2,070	63	3, 4	All arcs off.
19	8.25	2,070	43	2	
20	8.45	2,070	32	2	

N.B.—The P.D. waves are all to the same scale, but the current waves are to different scales.

Sheet A gives the curves obtained on January 20th, 1902, and Table VII. is the key to the reference numbers. Sheet B gives the curves obtained on July 26th of the same year, and Table VIII. is the corresponding key. Sheet C gives the voltage wave-forms of the various alternators running light, and also some miscellaneous waves, and

NG TWENTY-FOUR HOURS.

P.D ——— CURRENT ....

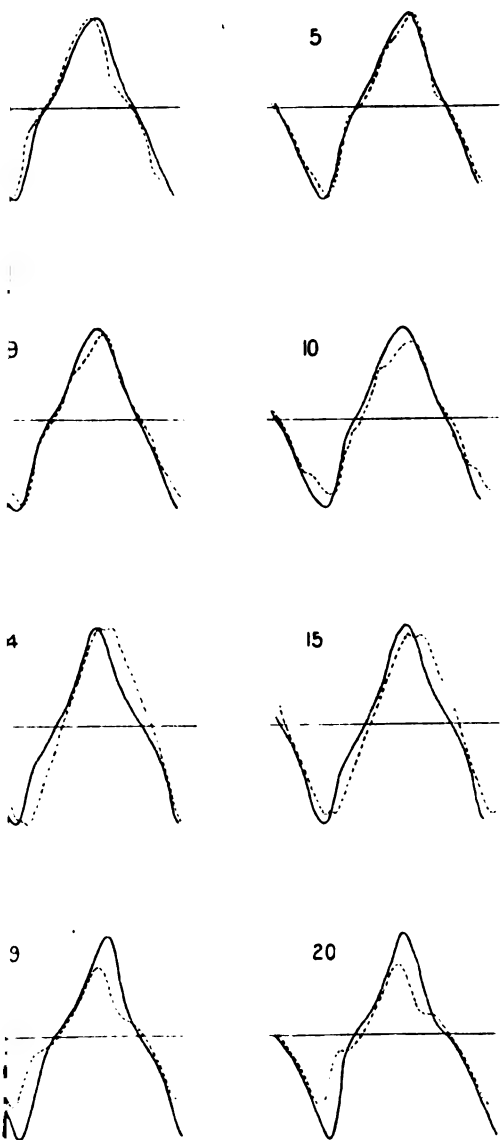


TABLE No. VIII.

Variation of Wave Form during 24 Hours.

No. of Curve, Sheet B.	Time.	Bus-bar Volts.	Total Amps.	Machines Running.	Remarks.
1	6.50	2,070	32	7	All transformers on. 5,000 volt cable on load.
2	7.25	2,075	70	7	
3	7.50	2,080	140	6, 7	
4	8.12	2,100	260	5, 6, 7	All arcs on.
5	8.58	2,115	510	5, 6, 7	Maximum load.
6	10.50	2,100	310	5, 7	
7	11.30	2,100	200	7	
8	12 mdnt	2,090	110	7	H.N. arcs off.
9	12.15	2,090	110	4, 7	
10	1 a.m.	2,090	100	4	Only a few transformers on.
11	2.55	2,060	85	4	
12	3.32	2,060	30	4	Some arcs off.
13	4.5	2,050	26	3	All arcs off.
14	7.5	2,060	18	3	5,000 volt cable off.
15	7.10	2.060	26	3	„ „ „ on.
16	10.50	2,060	26	1, 3	„ „ „ „
17	11.20	2,060	26	1	„ „ „ „
18	4.15	2,060	24	1	5,000 volt cable on and Rect. Arcs Circuit.
*19	6.40	2,060	30	1	5,000 volt cable and all transformers on.
20	7.30	2,060	30	7	„ „ „ „

* This current curve was actually taken before No. 1, and the volt curve interpolated from previous records.

N.B.—The D.P. waves are all to the same scale, but the current waves are to different scales.

Table IX. is the key to this sheet. The sine waves equivalent to the various voltage waves are shown by dotted lines. The normal periodicity is 60 per second.

The curves have not been taken at regular intervals of time, but only when, owing to some alteration in the kind or magnitude of the load, there was likely to be a change in the shapes of the waves.

The alternators are all of the iron core, slot wound, revolving armature type, with large percentage regulation. Nos. 1 to 5 were designed to be short-circuited with impunity. They are direct-coupled to their engines and, under normal conditions, run perfectly in parallel at all loads.

On comparing the two sheets A and B, the first noticeable point is the remarkably peaked waves in B. The only difference was the addition of a feeder working at 5,000 volts and 3·6 miles long, a few other 2,000-volt and 200-volt cable extensions, and also No. 6 alternator.

The effect of this increased capacity is to totally alter the shape of the current waves and to appreciably alter the voltage waves.

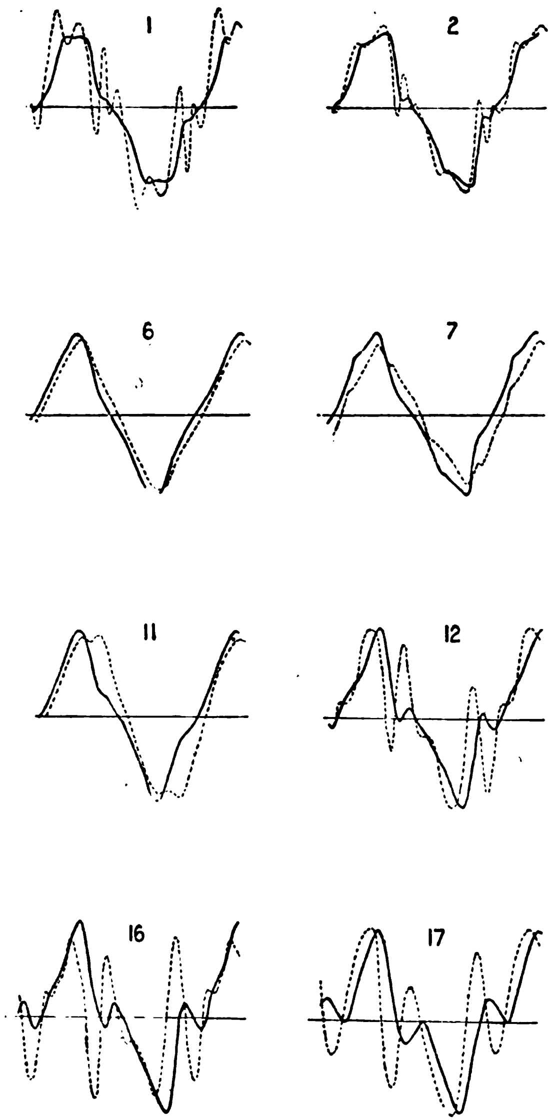
TABLE No. IX.

No. of Curve, Sheet C.	Description of Curve.	Alternator No.	R.M.S. Volts.
1	P.D. Curve 30 k.w. Motor-driven Alternator running light	M.A.	2,060
2	„ „ 120 k.w. Alternator running light	1	„
3	„ „ „ „ „ „ „	3	„
4	„ „ „ „ „ „ „	3	„
5	„ „ 250 „ „ „ „	4	„
6	„ „ „ „ „ „ „	5	„
7	„ „ 500 „ „ „ „	6	„
8	„ „ „ „ „ „ „	7	„
9	P.D. Curves of Rectifier, Applied and Rectified volts, Rectifier running on small Transformer loaded	...	Applied: 2,080 Rectified: 16·8
10	P.D. Curve 500 k.w. Alternator running light	6	2,090
11	„ „ „ „ „ „ „	7	„
12	„ „ Nos. 6 and 7 Alternators in parallel; synchronising current curve dotted	...	2,090 Current about 15 amps.
13	„ „ 30 k.w. Alternator running light at 15·3 ∿, on 5,000 volt cable through 200 volts — 2,000 volt transformer	...	2,045
14	P.D. Curve of 30 k.w. Alternator loaded to 16 k.w. running at 60 ∿, on 5,000 volt cable alone	...	2,050
15	Current Curve, 30 k.w. Alternator light at 30 ∿, on 5,000 volt cable	...	Current: 0·58 amp.
16	P.D. Curves of Primary and Secondary volts on 2,000 — 5,000 volt 100 k.w. transformer	...	Primary: 2,100 Secondary: 5,250

NOTE:—All the Alternators have slotted iron cores, revolving armatures and laminated poles.

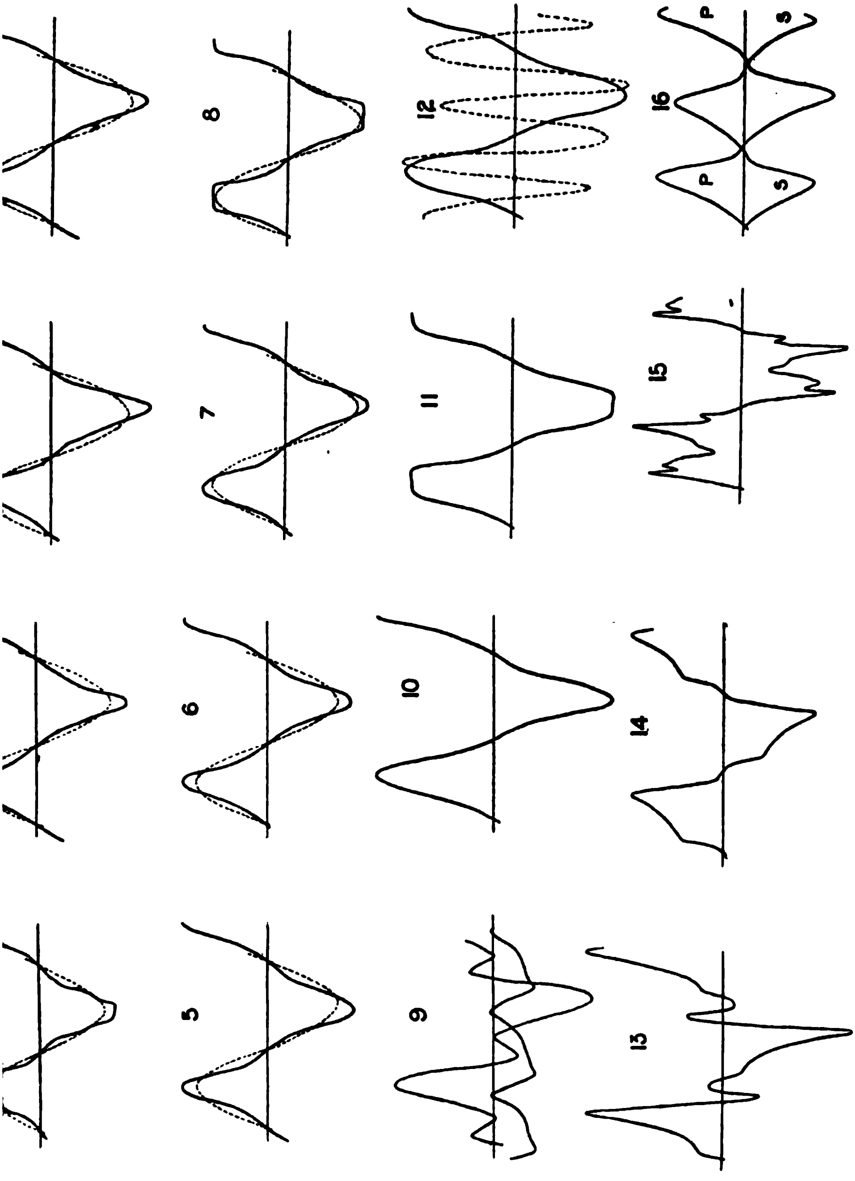
It is interesting to notice how, with the load consisting chiefly of cables, the current is leading. As the load increases, the current and voltage waves approach each other in phase and the irregularities are smoothed out. Late at night when the load is mostly arc-lighting, the current lags. Some very remarkable effects are produced by the flat-topped wave of No. 7 alternator, as shown in Curve No. 12, Sheet A, and Curve Nos. 7, 8 and 9, Sheet B.

On Sheet C the additional curves are exceptional, and show what remarkable effects may be produced by suitable combinations of capacity and inductance. These were obtained with the ordinary plant of the station in the course of some miscellaneous experiments, and they point out the necessity of not allowing abnormal conditions to arise in working, or the safety of the cables and transformers may be seriously



SHE

VOLTAGE WAVE FORMS OF ALTERNATORS, ETC.



SHEET C (SEE TABLE No. IX.).

endangered. Curves Nos. 10, 11, and 12 on this sheet show respectively the voltage curves of alternators Nos. 6 and 7 running singly and also in parallel. The dotted curve in No. 12 represents the synchronising current flowing between the two machines, its R.M.S. value being about 15 amperes. The voltage curve of the two in parallel is practically the mean of the separate curves. In connection with the general question of parallel running of alternators, the following result is interesting: On one occasion an attempt was made, for convenience in practical working, to join up two machines in parallel through two concentric cables, each about four miles long. Under these conditions the machines would not keep in phase at all, although under normal conditions they ran perfectly together.

METER LOSSES.

The question of meter losses now remains to be dealt with.

There are in use in the district being considered rather more than 1,200 meters, and the same number of Wright's Demand Indicators. About 1,000 of these meters are Thomson meters, and the rest of the Westinghouse Co's manufacture.

The shunt losses are by far the most serious, as these go on continuously, and they amount to a total of 37,400 units per annum.

As is well known, the shunt loss of a Thomson meter is rather high; the Westinghouse meter, however, only takes about 1 watt in the shunt.

The series coil losses, worked out from the load curves for private lighting, only reach a total of 1,350 units per annum for both meters and demand indicators. This low figure is due to the short hours the meters have any appreciable load on them, and to the fact that in the majority of cases the meter is never run at its rated full load.

In fact, the total amperage of meters installed is about 3·6 times the maximum current used for private lighting.

It is evident that a large economy could be effected by abolishing the shunts altogether and using ampere-hour meters. The only difficulty is the variation of the consumers' pressure from the supply standard.

In very few cases, however, is the variation more than the limit of inaccuracy allowed in the meters, and on the average the standard pressure will be very nearly kept to.

Using an energy meter, the consumer who gets a good pressure pays a little more for his ampere-hours than he otherwise would, and is well satisfied. In the case of an ampere-hour meter, the consumer with a bad pressure pays for rather more units than he uses, but he will not notice the difference in his bill, and he will complain of the bad light in any case.

There are further advantages in using ampere-hour meters, viz., cheapness, ease of installing and less risk of breakdown.

The large loss in the shunts given above is due, of course, to the particular type of meter in use, but the Thomson meter is not the worst in this respect, though it is far from being the best.

So far, the losses have been enumerated without much reference to

TABLE No. X.

Summary of Losses.

	Quarters.								Year.		Percentage of Units Generated.	Percentage of Units sent out.
	May, June, July.		Aug., Sept., October.		Nov., Dec., January.		Feb., March, April.					
Losses in Switchboards and Connections ...	...	600	...	2,000	...	5,000	...	2,400	...	10,000	0·51	0·54
Cable Losses:												
H.T. Leakage and Dielectric Hysteresis ...	4,100	...	4,100	...	4,100	...	4,100	...	16,400	...	...	...
H.T. C^2R	3,400	...	10,600	...	22,200	...	11,000	...	47,200	...	...	...
Cable Losses:												
L.T. Leakage and Dielectric Hysteresis ...	500	...	500	...	500	...	500	...	2,000	...	...	...
L.T. C^2R	6,800	...	16,500	...	25,400	...	17,500	...	66,200	...	...	...
C^2R Loss in H.T. and L.T. Arc Cables	4,640	...	8,710	...	13,820	...	10,030	...	37,200	...	...	...
Total Cable Losses	...	19,440	...	40,410	...	66,020	...	43,130	...	169,000	8·7	9·2
Transformer Losses:—												
Core Loss	26,000	...	27,000	...	29,000	...	27,500	...	109,500	...	...	...
Copper Loss	9,500	...	17,400	...	19,400	...	17,400	...	63,700	...	...	...
Total Transformer Losses	...	35,500	...	44,400	...	48,400	...	44,900	...	173,200	8·9	9·4
Meter Losses:—												
C^2R	60	...	370	...	850	...	470	...	1,750	...	...	...
Shunt	12,500	...	12,800	...	13,400	...	12,800	...	51,500	...	...	...
Total Meter Losses	...	12,560	...	13,170	...	14,250	...	13,270	...	53,250	2·7	2·9
Total Losses	...	68,100	...	99,980	...	133,670	...	103,700	...	405,450	20·8	22·0
Per cent. of Units sent out	...	33·4	...	24·8	...	18·5	...	20·5	...	22·0	...	...
Units Generated	...	223,000	...	423,000	...	764,000	...	538,000	...	1,948,000	100	...
Units sent out...	...	204,000	...	403,000	...	724,000	...	506,000	...	1,837,000	94·4	100
Units sold (*a*)	...	135,900	...	303,020	...	590,330	...	402,300	...	1,431,550	73·4	78·0
Units sold (*b*). Sum of Consumers' Meter Readings	...	139,000	...	344,000	...	638,000	...	381,000	...	1,502,000	77·0	81·7
Per cent. Units sold to Units generated... ...	...	61	...	72	...	77	...	75	...	73·4 (*a*) 77·0 (*b*)	...	...

DISTRIBUTION LOSSES.

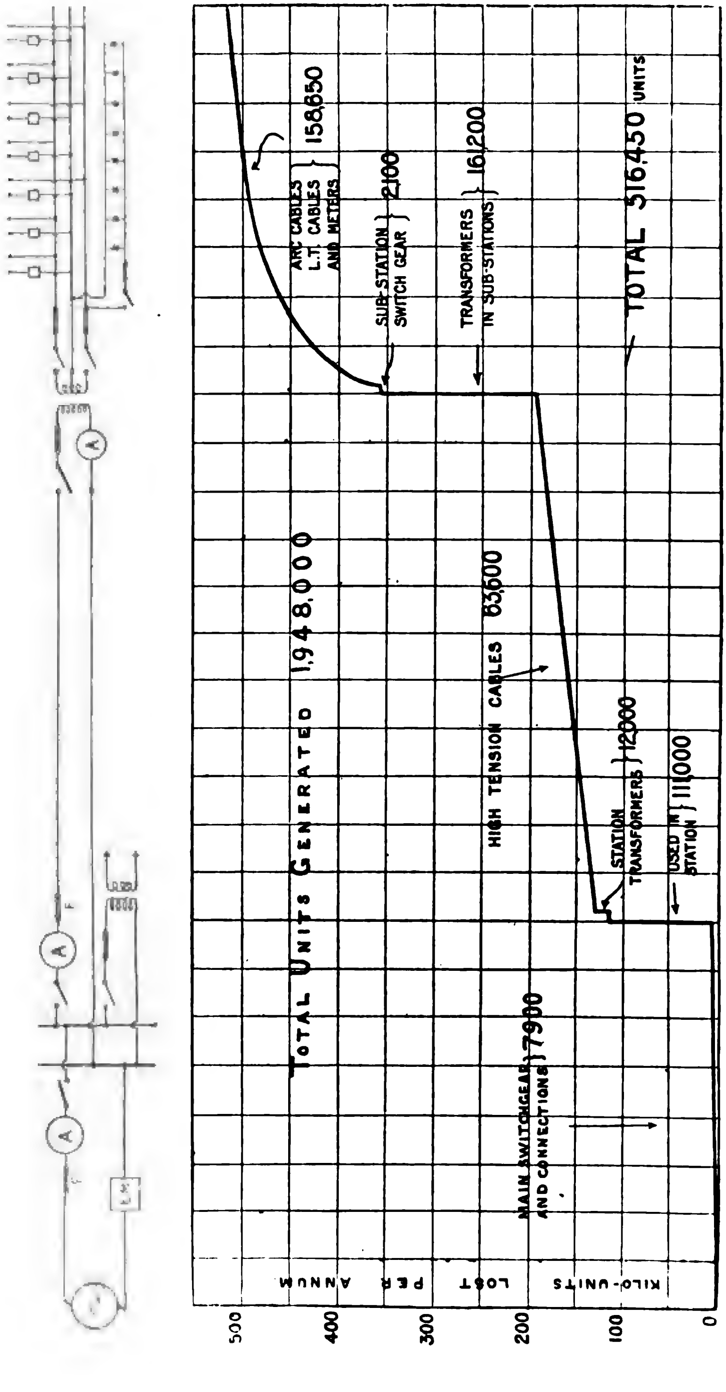


DIAGRAM No. VII.

the total output of the station. In Table No. X. the whole of the losses are summarised and expressed as percentages of the total units generated and the total units sold.

Diagram No. VII. is a graphic representation of the losses as they occur in the system.

It will be seen from the Table that the calculated loss is 22 per cent. of the units sent out of the station. From the actual sum of the consumers' meter readings, however, the loss appears to be only 18·4 per cent. This difference of 3·6 per cent. is no doubt partly due to a rather liberal estimate of the losses in some cases; numerous approximations are required, and it is impossible to calculate the losses with great accuracy. It may also be partly due to small errors in the meters. The total units generated depend on the average accuracy of seven meters, whilst the total sold depends on 1,200—a difference of 2 or 3 per cent. may thus easily occur.

There is a further side to the question which, however, as it hardly comes within the scope of this paper, will be briefly dealt with. It may be economical to waste energy as long as interest has to be paid on borrowed money. It is, of course, possible to reduce C^2R losses at any rate to a negligible amount, by putting in enough copper, but it is not economical to do so.

It is the duty of the engineer to design a system which shall give the best result for the least annual expenditure; he must avoid losses in transmission up to the point where the expense of avoiding them becomes greater than the cost of the energy lost. A case illustrating the comparative advantages of two alternative schemes is the following:—

A certain portion of the district considered in this paper was originally supplied with alternating current from four sub-stations, fed at 2,000 volts. After a few years the load became much heavier than at first, and it was found both more economical and advisable for other reasons to change the supply to direct current without transformation, using the same low-tension mains, instead of adding to the section of the existing cables. The total losses per annum under the old system amounted to 49,100 units. With the new system for the same load the losses are 40,300 per annum, so that there is a saving of 8,800 units in favour of the direct-current supply, and the cost of the alteration was considerably less than that of the other alternative.

The average distance of these sub-stations from the generating station is 1,290 yards, or about three-quarters of a mile, and the maximum load is about 400 k.w. in all.

With regard to the means for reducing the losses in general to a minimum, the methods to be adopted have been mentioned under the various sections of this paper, but they may be summarised here. Primarily good design is necessary; after that, care must be taken to remove useless causes of waste during times of light load.

The cure for waste of energy in switchboards and station connections is simple design, good workmanship, and choice of suitable positions. Cable losses may be reduced, assuming suitable dielectrics have been selected, by switching off high-tension cables not required for

load, but, as in most cases the saving by doing this is small, the extra risk of cable breakdowns more than counterbalances it.

C^2R losses in the low-tension system may be cut down by interconnecting the network so as to use all the copper laid down, to the best advantage. Fuses between the various sections must be relied on in case of breakdown if this is done.

Transformer losses during light loads are, of course, reduced by switching out transformers which are not necessary. This practice is not, in the opinion of the authors, detrimental to the safety of a well-made transformer. It may certainly pay in some cases to scrap transformers of an old and wasteful type, rather than to use them until they are worn out. It may be worth while to either artificially alter the wave shape during the day, or to run machines with a peaked wave in order to reduce the core loss.

It is hardly admissible to alter the frequency unless no motors whatever are in use.

To remove the largest source of loss in meters, shunts should be abolished, as discussed in the section on meters.

Although this paper deals with the Croydon system of distribution, the arguments hold good generally, whether the supply is by means of alternating or direct current.

The question of losses in tramways or power schemes is considerably modified, however, by the altered conditions of working.

There are in such cases only a few hours of light load instead of the larger part of the day, and as the losses will be practically all C^2R loss in the cables, much heavier copper must be put in to secure the most economical working.

The losses detailed in this paper are incurred in a system which is indisputably, on the whole, well arranged and economically worked. The district has the disadvantage of being a very extended one, so that the number of consumers per mile of mains is small. This accounts for part of the large C^2R losses, but even so the remainder is of very considerable magnitude, and there must be many supply systems working under worse conditions.

The engineers of these systems will, however, probably feel hurt if they are told that they are guilty of slowly, but surely, throwing away the coal resources of the Empire, and that they are, therefore, neither serving their profession or their country in the highest degree.

In conclusion, the authors wish to heartily thank Mr. Minshall for his help and many suggestions, and also to thank his successors at Croydon for their kind permission to complete the necessary experiments and to publish these results. Several members of their staff have also merited thanks for much valuable assistance and unflagging interest in the experimental work. A tribute is due to Mr. Duddell for having placed on the market so beautiful an instrument as his oscillograph; but for the interest attached to the use of this instrument, this paper would not have been written.

INDEX TO TABLES.

INDEX TO DIAGRAMS.

INDEX TO CURVES.

Mr. M. B. Field then read an abstract of his paper, entitled "A Study of the Phenomenon of Resonance in Electric Circuits by the Aid of Oscillograms" (see above, page 647), read before the Glasgow Local Section.

President. The PRESIDENT: I will not occupy the time of the Institution in complimenting the authors of these papers; everybody who has looked at them knows how much we are indebted to them for their labours.

Mr. Leonard Andrews. Mr. LEONARD ANDREWS: Whilst I have been very interested in both the papers we have listened to, I have only a few remarks to make on the first one. This question of distribution-losses has been troubling us at Hastings for some years. Until two years ago our losses in the summer months amounted to about 50 per cent. of the units generated. Various alterations were made to reduce these losses, and last year, during the months of June and July, they only averaged 27·3 per cent. of the units generated. To roughly locate these remaining losses we fixed meters in the sub-stations between the low-tension transformer 'bus-bars and the distributing 'bus-bars. By this means we were able to compare the units generated, the units turned out from the sub-stations, and the units metered to consumers. The losses in the high-tension feeders and transformers during the two months referred to amounted to 16·8 per cent. of the units generated, and the losses in the low-tension mains and consumers' meters to 10·5 per cent., thus making the total distribution-losses 27·3 per cent. of the units generated. It appears from Table 10 of the authors' paper that the corresponding losses at Croydon amounted respectively to 20·8 per cent., 9·8 per cent., and 30·8 per cent. of the units generated during the summer months. At Hastings the whole of the high-tension feeders and transformers are cut off shorly after 11 p.m., and are left disconnected until sunset the following day. During the hours of light load the supply is maintained through the low-tension network alone, from one sub-station adjoining the works. On page 16 of their paper the authors suggest that the dielectric hysteresis losses are insufficient to make it worth while to cut off the high-tension feeders during the hours of light load, when the risks involved in doing so are considered. They recommend, however, that some of the transformers should be switched off to reduce the transformer-losses. They appear to have overlooked the fact that the risk incurred in switching transformers on and off is probably quite as great as switching feeders on and off, added to which it is a risk which cannot be so easily dealt with. If the feeders and transformers are switched off simultaneously, as is done at Hastings, some simple cable-charging device can be used for this purpose, and thus the rise of pressure in both feeders and transformers can be prevented. That rises of pressure do often occur when a transformer is excited, either from the low-tension or high-tension side, may be seen by the aid of an oscillograph or by connecting a spark gap across the primary terminals. If the spark-gap is adjusted to just not break down at double the normal working pressure of the primary of the transformers, a spark will jump across the gap at the moment of connecting the secondary windings to a low-tension source at normal

pressure. Quite apart from the reduction of dielectric hysteresis losses effected by switching off feeders during the hours of light load, there is a great advantage in having the whole of the high-tension system dead in the daytime for alterations or testing. The variation in the shape of the curves that the authors have shown is very interesting. We have also noticed that we get a very different shaped curve on light load to what we get on full load, though this difference only appears to be noticeable on iron-cored machines. The authors refer to the fact that they have found that, under certain conditions, the current curve lags behind the E.M.F. curve. I have been rather surprised to notice that at Hastings under no conditions do we get a lagging current. Even when the load is made up of 50 per cent. of arc lamps and magnetising current the current still appears to lead. This is probably due to the fact that there are several miles of vulcanised rubber cable connected to the system. The authors suggest that meter losses might be reduced by doing away with the shunt-windings in meters. I think it would be found that to do this would tend to introduce another, and a much more serious, source of loss, namely, that due to the meters failing to start on light load. With very small meters, that are only expected to carry a maximum load of two or three amperes, this difficulty does not exist, and it is probable that with these meters the saving effected by doing away with the shunt-windings would more than counterbalance any loss due to consumers being supplied at a pressure two or three per cent. above the declared pressure. Larger meters can, however, only be relied upon to start on light loads if they are constructed with shunt-windings. We effected a very considerable saving a few years ago by taking out the whole of our ampere-hour meters and replacing them by watt-meters, in spite of the losses introduced due to the shunt-windings of the latter. Mr. Leonard Andrews.

Major P. CARDEW: I will not detain you very long, because, although I made three attempts during the last week to read these very interesting papers, they were always stolen from me, and I have not been able to get through them. The point that forcibly occurs to me, looking back to the time when we were settling regulations, is how lucky it was that we stipulated that all cables were to be tested with twice the working pressure with one hour, seeing what a tremendous amount of increase of pressure you get from these exaggerated ripples. If that is carried out, I think the cables ought to stand all that they are likely to be subjected to, even from the amount of resonance that may take place. There is no doubt that the charging of a cable is, in all respects, very much like dealing with a live load on a bridge. I think a practical way to look at it is that the cable must be strong enough to stand the extra stress which comes upon it. At the same time, it occurs to me that, with a view to diminishing to some extent the danger to cables on systems with high pressures, something might be done in modifying the switching arrangements —the switching on and off. As far as I have read the discussion on this paper, and on all other papers, it is always taken that the absolute charge—the contact—is an instantaneous thing; but when we see what a lot may happen during one period of a fiftieth of a Major Cardew.

Major Cardew.

second it occurs to me that the absolute contact is not by any means instantaneous, and that the cable is really eased up at high pressures—pressures of 5,000 volts and upwards—by the arc which takes place as the switch is closed. And, more than that, we must consider the effect of the closing switch as being to some extent an adjustable condenser, rapidly increasing its capacity and in series with the capacity of the cable. That being so, of course the voltage condensed on the moving contacts of the switch is continually diminishing as the charge increases; and, on the other hand, the voltage condensed across the cable is gradually increasing all that time. By some arrangement which will give more capacity effect to the switch as it closes, I think very considerable relief could be obtained.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Members.

Daniel Coyle.
Joseph Wilkinson.

Associate Members.

Rooke Ainsworth.
Edward Calvert.
Samuel McLean.
Charles Andrew Newton.
John Walter Parr.
Charles Norman Robinson.
Walter Stewart.
George Gordon Tomkins.

Associates.

Arthur Baker.
James Stephen Blackwell.
Joseph Boyce.
William John Charlton.
Thomas Dow Frew.
John Jamieson.
Thomas William Storey.

Students.

Charles Reed Allensby.
William George Herbert Cam.
Albert W. Deakin.
William Rowland Ding.
Thomas Ellis.
Reginald Woolton Fowler.
P. L. R. Fraser.
James Frederick Gay.
Alexander Lindsay Glegg.
Masanoske Hayashi.
Kenneth Horton.
William Howes.
Clarence Hambly Hughes.
Alfred James Munday.
Thomas George Partridge,
John G. Potts.
Morgan Howell Rees.
Alfred Ernest Scott.
Frederick Smith.
Richard Edward Wellard.

The Three Hundred and Ninety-first Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, March 26, 1903—Mr. JAMES SWINBURNE, President, in the Chair.

The minutes of the Ordinary General Meeting held on March 12th were taken as read and signed by the President.

The names of new candidates for election into the Institution were taken as read, and it was ordered that these names should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

From the class of Associate Members to that of Members—

Reginald Page Wilson.

From the class of Associates to that of Members—

Stephen Stewart Goodman.

From the class of Associates to that of Associate Members—

Leonard Breach.
Edward Macgregor Duncan.
Arthur Frederick Malyon Gatrill.
Thomas McGill.
Herbert James Read.

From the class of Students to that of Associates—

Percy Meares Crampton.
Robert Saunders Newton.
Richard Lloyd Pearson.

Messrs. F. Graham and A. G. Inrig were appointed scrutineers of the ballot for the election of new members.

The PRESIDENT: The Students have been working very hard, and have got up a large subscription in aid of the Building Fund. They have collected no less than £83 6s., and after deducting the various small expenses, there is a balance of £79 10s. 6d. to add to the Building Fund. I am sure the Institution would like me to read this letter :—

"*March* 26, 1903.

"DEAR MR. MCMILLAN,—I enclose the balance sheet (which is a copy of my own) of our Students' Subscription List to The Building Fund of the Institution of Electrical Engineers. This fund was opened on January 1st and closed on March 30th last, and through our efforts we have been able to collect, as you will see, a net amount of £79 10s. 6d. By a motion of the Committee, I am not to give you a list showing the amount subscribed by each student, but just a list of the names of those who have subscribed ; this list I will send you, together with a cheque for the balance I have in hand, in the course of a day or so. I also

enclose a copy of the letter that was sent out, and hope these will reach you in time to be placed before the Council this evening. The total number of Students who have subscribed is 644, although included in this number are some Students who are studying electrical engineering, though not Student Members of the Institution. My Committee are extremely pleased with the result of this movement, as it shows that the Students recognise the desirability of a home for the Institution.

"Believe me,

"Very sincerely yours,

"HAROLD D. SYMONS."

Donations to the *Library* were announced as having been received since the last meeting from Messrs. C. Bright, C. Naud, and Whittaker & Co.; to the *Building Fund*, from Messrs. B. Balaji, S. Evershed, and J. F. Henderson; and to the *Benevolent Fund* from Mr. W. E. Russell, to whom the thanks of the meeting were duly accorded.

The PRESIDENT: I have to announce the result of a Special General Meeting of the members, held for the purpose of altering the Articles of Association. There were not many alterations, and I will just explain the principal ones. The first is to give the Council the power, which is given in most Societies, of removing at their discretion any one who is either a bankrupt, on the one hand, or on the other hand—the two things have nothing to do with each other—a felon. That is a Clause which is inserted in most Articles of Association. I would point out that it does not by any means indicate that supposing a man were unfortunately to become bankrupt he is to be expelled from the Institution, but supposing a man were a fraudulent bankrupt, or it was supposed that he was a fraudulent bankrupt, it might be very necessary to remove him; but unless there is some such rule as this the Council would not be able to do so without practically saying he was a fraudulent bankrupt, and that might lead the Institution into an action for slander, libel, or something of that sort. As the Article has been altered, in extreme cases it gives the Council power to take action. The next alteration is with regard to the Vice-presidents. Under the alteration two Vice-presidents retire every year. The idea is that it does not follow that every Vice-president should in the ordinary turn become President. It is rather difficult under the old rules to elect a member a Vice-president unless you desire to make him President also, and there are a great many people who would be very useful as Vice-presidents without necessarily being very well qualified to serve as President. It also gives us a bigger number to choose from. The arrangement is that in future two Vice-presidents will always retire, and the President must be chosen from some one who has been a Vice-president; so that a man who has once been a Vice-president is eligible for the Chair. By that means we will get a number of people, as it were, in stock to choose from, and it is felt that that will be better for the Institution. The only other alteration of any importance which I think I need mention is that the

Associate Members are now to have the power of voting with the Members in any important matter, such as altering the Articles of Association, or anything of that kind. The Council feel that the Associate Members and the Members only differ in degree, and that they ought to be one body. The last alteration is a matter of form, which, I believe, is legally unnecessary; it provides that every new member shall promise to agree to the rules of the Institution, and so on.

As I mentioned at our last meeting, it is very important that the Institution should have a President who should not only take charge of the Institution during the time of the International Telegraph Congress which is to be held in London, but should also be in the Chair early enough to make his arrangements for taking over the control of the Institution during the whole time. I sent in my resignation, as I said I would, and the Council have elected Mr. Gray to take the place of President. I can only say that I have the greatest pleasure in resigning in favour of Mr. Gray. Mr. Gray will now have time to organise the entertainments of the Congress in a way that I feel sure you will find will do great honour to the Institution. I have great pleasure in resigning in favour of Mr. Gray, and I will now ask him to take the Chair.

[Mr. Swinburne then vacated the Chair, which was taken by Mr. R. K. Gray.]

Mr. J. GAVEY: Gentlemen, before the new President addresses you, I should like, if you will allow me, to intervene with a few remarks. The post of President of this Institution confers high honour on the holder, for he is for the time being the head of our profession. It also entails very onerous labours, labours of which, perhaps, only those who are on the Council, or who have served on the Council, are really good judges. You are able to appreciate the able manner in which the past President has upheld the high traditions of his office in presiding over your meetings. I, as a member of the Council, can testify to the great business aptitude with which he has conducted the deliberations of the Council, and with which he has managed the affairs of your Institution. Gentlemen, great professional ability or great business acumen compel admiration, but there are other qualities which command esteem and regard; and personally I can say that your retiring President has, during his year of office, shown such an amount of tact and courtesy in dealing with the affairs of the Institution, that he leaves behind him a body of men, who, I venture to say, consider themselves his personal friends. If you want an illustration of the tact and courtesy with which he has dealt with his duties, I need only call your attention to the graceful and generous manner in which he has retired before the expiry of his period of office, in order that his successor may have the fullest opportunity of organising the reception of the International Telegraph Conference in the manner most satisfactory to himself and to the best advantage of the Institution. I have much pleasure in proposing a very hearty vote of thanks to the retiring President.

Mr. W. H. PATCHELL: Gentlemen, the duty which devolves upon

me to night should properly devolve upon one of the Vice-presidents, but they are unfortunately absent owing to the Dinner to Sir William White, which has called for the personal service of them all. Our past President—I am sorry to have to call him so so soon—ought to have been there also, and it is only another instance of the courtesy with which he has invariably treated us here that he has foregone so much of the dinner, although he hopes presently to get in for the ices. Mr. Gavey has told you something about our past President's handling of the Council, and you have seen for yourselves the way in which he has handled these meetings. As a specimen of his tact, I need only refer to the fact that he had hardly got into the Chair when he had to head the deputation to the Board of Trade, and I think the handling of that deputation was just a masterpiece of diplomacy. No words from me could give you any higher opinion of Mr. Swinburne than he has earned for himself. He is only a young man, and I hope we may live to see him serve us again when, instead of having an abbreviated year of office, I hope we may be able to give him a leap year.

The resolution was carried with acclamation.

Mr. J. SWINBURNE: Mr. President and gentlemen, it is very difficult indeed for a man to reply to such very kind speeches as I have heard to-night, and to reply after a vote of thanks has been carried in the way in which you have carried this one. I can only say that being your President is the greatest honour that can be conferred on any member of the profession. But in my case I have felt that it was not only a great honour but an immense pleasure. I have had nothing but pleasure throughout the time I have had the honour of being your President. I am very sorry to resign in one sense, and in another sense I am very glad indeed, because, though I have enjoyed my time very much, and everybody has treated me with the greatest kindness, I cannot help feeling that in Mr. Gray you have a more experienced man, a man who will be about the best President you possibly could have. I thank you, gentlemen.

The PRESIDENT (Mr. R. K. Gray) said: Gentlemen, before proceeding to the discussion of the papers that we have before us to-night, I desire to say, in as few words as possible, that I appreciate very much the honour which has been conferred upon me by the Council, and I sincerely hope I shall be able to follow the traditions of my predecessors in this Chair. I will not occupy your time any longer, except to tender you my best thanks for the very kind way in which you have received the announcement which Mr. Swinburne has made to you.

RESUMED DISCUSSION ON PAPERS ON "DISTRIBUTION LOSSES IN ELECTRIC SUPPLY SYSTEMS," BY A. D. CONSTABLE, A.M.I.E.E., AND E. FAWSSETT, A.I.E.E., AND "A STUDY OF THE PHENOMENON OF RESONANCE IN ELECTRIC CIRCUITS BY THE AID OF OSCILLOGRAMS," BY M. B. FIELD, M.I.E.E., A.M.I.C.E.

Mr. Minshall

Mr. T. H. MINSHALL: I think the peculiar value of these two papers which are before us to-night, dealing as they do with the

oscillograph, is not so much the accuracy of the results which are given, although many of those are very interesting, but the number of new suggestions which they make to men engaged in practical engineering. Mr. Constable's paper, together with the diagrams which are given, has come in a sense as a revelation to a great many station engineers. A good many of us did not realise, until the oscillograph was made a practical instrument, what extraordinary wave-forms we have to deal with; and when one sees some of the very peculiar shapes which are shown in some of the tables, more especially in Table No. 4, one is not at all surprised at almost any form of resonance effect or breaking-down effect which one hears of in actual practice. There are several points that occur to me which have not had much attention drawn to them before. One of those is the question of the enormous loss which goes on in all central stations. One does not realise that actually 25 per cent. of the total output of a station is, at the present time, lost. Of course it must be borne in mind that of that loss a great deal occurs at the top of the load, and that hence the cost of generation of those units must be taken as the maximum possible. Taking these units given in the paper, and allowing the average cost of generation of the total of 173,000 units, we get between £200 and £300 a year actually lost; if you can save them, or prevent them going in any way, it is all profit. I do not know that there are any other points that occur to me in connection with the first part of the paper. The dielectric hysteresis is the part which appeals to me as the most interesting, although possibly it is not the one of the greatest practical importance. This paper originated with some experiments that Mr. Constable made for me in connection with the discussion on Mr. Mordey's most interesting paper last year. Members may recollect that in that paper Mr. Mordey showed some results with a power-factor of the order of 0·1. The Institution at the time as a whole, I think, did not entirely agree with those figures, and we made some experiments at Croydon to see if such a thing were possible. It so happened that the experiments we conducted were not on a paper cable, but on a vulcanised bitumen cable, and we got results almost exactly agreeing with Mr. Mordey's. I do not pretend that anybody believed them; so we spent some time and trouble since then in attempting to produce the results by several methods. I think Mr. Constable shows here fairly conclusively that with a cable of this peculiar construction and material, it is quite possible to get a power-factor of the order of 0·1. As a matter of fact, when he comes to deal with jute cables and paper cables, of course then the results which he obtained are more in accordance with those which were obtained by so many investigators last year. There is no doubt, I think, that the ordinary power-factor of the ordinary paper cable is of the order of 0·01 or 0·02. I do not think it would be very much higher, although some of the jute cables seemed to go as high as 0·03, but I should think 3 per cent. is the maximum power-factor which is obtained from any of these cables in commercial use. Mr. Constable gives on page 713 a very interesting *résumé* of the various methods which are applicable to a measurement of this

Mr. Minshall.

Mr. Minshall.

kind. It is very important indeed that one should clearly realise the great difficulty there is in conducting investigations into what he has called dielectric hysteresis. The five methods he has given here are all of them to a certain extent practical, provided that you have sufficient time and apparatus at your disposal. The first one certainly appears to be one of the best. When I was in America last year I discussed the matter at some length with Mr. Steinmetz and Mr. Berg, and they were of the opinion that they would use the one the authors used; but when I showed them some of the wave-forms in the diagrams on page 711, they agreed that it was not perhaps such a good method to use as they had previously thought. My own conclusion is that if it is not possible to use a calorimetric method, the only method on which one could really rely with bad wave-forms is No. 3, that is, the direct measurement of increased power necessary to drive an alternator when a cable is switched on. Of course at the first glance it appears as if the measurement to be made is so extremely minute that it is impossible to measure it; but a small motor alternator, carefully driven, with the supply at the direct-current end measured on a potentiometer, would enable one, on a long cable, to get results of very considerable accuracy. The difficulty is that the wave-form of the alternator itself, unless care be taken, gets altered during the experiment; that is to say, you may have practically a sine wave before you put the cable on, and then immediately you put it on you get one of the forms shown in Table 4. I know that Mr. Constable took very great efforts to get over that. He took a motor alternator and loaded it up with 30 kilowatts, and switched a cable on the losses in which added 1 kilowatt extra load, hoping thereby he would preserve the same wave-form as before. But he found it was impossible to be quite sure, and I am afraid the results he obtained from that are more or less negative. If one could get a sine-wave machine, and potentiometers of sufficient accuracy, it is a method which promises a good deal in the hands of a really careful investigator. The author has not drawn attention to one very interesting experiment which we made some time ago at Croydon to show that the current, and even sometimes, owing to the alteration in wave-form, the watts flowing into a cable on open circuit may be actually greater than when some load is put on at the end. We took a long cable of about 7,000 yards, put on an alternator, and measured the capacity current flowing into the cable. We then added a couple of transformers, open-circuited, whose core losses amounted to two kilowatts, the result being that the current entering the cable was measurably smaller than before. That has been repeated a good many times, but I do not think he draws attention to it anywhere here. It merely shows that if properly arranged the capacity of a cable on a large net work may be of advantage rather than otherwise. As a matter of fact it is not actually so deleterious to the supply as possibly is sometimes imagined. I do not think there are any other points that I remember at the time in that connection, but I should like to refer to a remark made in connection with telephones. We had much trouble from Sydenham and Croydon and on to Purley with the telephone cables; we

Mr. Minshall

were a great nuisance to the National Company, and a great deal more nuisance to ourselves. Eventually the manager of the National Telephone Company in that neighbourhood and myself investigated the matter at some length and came to the conclusion that you can take a concentric cable, put it in a lead sheath, in an iron trough, and lay another cable by the side of it also in a lead sheath, and still get any amount of stray field, or what appears to be stray field: you can get enough humming to make it practically impossible to hear on the telephone. Some people say it is leakage, others static effect. We investigated very carefully to find if it was leakage, but we satisfied ourselves entirely that it was not electrical leakage at all. When the current increased in the evening the sound was very greatly increased too; in the day time, when there was very little current flowing in the cable, there was very little noise in the telephone. We came finally to the conclusion that the only really satisfactory way of running telephone cables near high-tension cables was not to trust to any sheathing whatever, but to increase the distance. I shall be glad to hear the experience of other engineers on that point, because it is one which caused us a great deal of trouble. I will not detain the Institution by drawing attention to the number of other uses which the oscillograph is going to have in the future; but there is one in particular which appealed to me, namely, that in specifying high-tension machinery it is now becoming customary to specify the wave form of generator, rotary, or motor generator as the case may be. One has not only to specify voltage, and that sort of thing, but one has to say what sort of wave the machine is to give. Hitherto it has been easy to specify, but it has been difficult to see that you were getting what you wanted. Here you get an opportunity of seeing that the contractor is complying with a specification, an opportunity which hitherto has been impossible. I think every alternate-current station engineer should get his directors to agree that the sum expended on this little apparatus is very well spent indeed.

Mr. Duddell.

Mr. W. DUDDELL: Messrs. Constable and Fawssett have used three different methods to determine the losses in their cables, viz.:—

(1) The wattmeter method.
(2) The wave-form method.
(3) The extra power required to drive an alternator method.

Of these methods I have no doubt that the wattmeter method is one of the best, if not the best. If a suitable wattmeter and suitable series resistances for the pressure coil are used, accurate results can be obtained, in spite of the wave-forms being as irregular as those shown in Mr. Constable's paper. I hope that Diagram 4, which shows the wattmeter connection, is wrong. In it the pressure coil of the wattmeter is shown connected direct to a resistance marked R_4, with no non-inductive resistance in series with it. If that was really the case, very large errors were introduced. Judging from the oscillograph connections, this appears to have been the case, for the terminals of the resistance R_4 are shown connected straight to the oscillograph, which only requires 1 volt to operate it.

From the text it seems as if they used some resistance in series

Mr. Duddell. with the pressure coil of the wattmeters which they have omitted to show. In any case it would be of great interest to know the values of the resistance, self-induction, and capacity of the pressure coil circuits for each of the wattmeters they used. I hope the authors will be able to give these figures, as they will enable a more accurate estimate of the obtainable accuracy to be formed.

Coming next to the methods of calibrating the wattmeters on power factors less than unity, they state that they calibrated them with a lagging current by using a choking coil. If the choking coil is properly constructed, there is not much difficulty in calculating the true power losses in it. They also state that they obtained a leading current having a power-factor of 0·14. I should like to ask them how they calculated the value of the power-factor in that case. Diagram No. 3 throws no light on the matter whatever, and, as far as I can gather, it is impossible to calculate the power-factor unless they either assume a pure sine wave, or analyse the actual wave used, and calculate each term of the series representing the wave-form separately. There is no indication that this was done. If the actual wave used is that given in Fig. D., which is far from being a sine wave, and if they assumed a sine wave in their calculations, then the calculation of the 0·14 power-factor and the calibration of the wattmeters with leading currents is inaccurate. I hope the authors will explain this matter fully in their reply, as it affects the accuracy of all their wattmeter measurements of the cable losses.

[*Communicated May 6th.* The ingenious method described by Mr. Constable in his reply neglects the self-induction of the fixed coil of his wattmeter and assumes the current A_2 through it in phase with the applied volts V′. Was this self-induction negligible compared with the resistance?]

Ever since Mr. Mordey's paper, Mr. Mather and myself have been working on the design of a satisfactory wattmeter and series resistance, especially for use on very low power-factors, and we have now designed and had in use for some months an astatic wattmeter which is quite free from metal parts in the frame, which has the minimum amount of metal necessary in the coils, and which gives a good deflection, even with very low power-factors. In fact, the wattmeter is so sensitive that with a power-factor of 0·1 you get a complete revolution of the torsion head, so that a power-factor of 0·01 is perfectly easy to read with a high degree of accuracy. We have also designed and constructed special forms of resistances for use in series with the pressure coil, for, as is well known, the errors in these resistances are very often very much bigger than that due to the self-induction of the pressure coil of the wattmeter itself. We have made numerous experiments to test the accuracy of this wattmeter, and we hope to have the opportunity later on of describing it and the resistances. With regard to method No. 2, the wave-form method, it is not very suitable for very irregular wave-forms, unless the wave-forms are actually photographed. It does not suffice to photograph a mean wave-form, as Mr. Field has done. You must get an individual pressure curve and the corresponding current curve belonging to it, and you must work the result out from the

contemporaneous values of the P.D. and current obtained from those two curves. You must not take the P.D. curve of one period and integrate with the current curve of the next, nor take a mean of, say, ten P.D. waves, and work out the power-factor with the mean of ten current waves; you must take each individual pair of curves together, because they may vary considerably. I have on the table the apparatus I use for obtaining photographic records, which records the individual waves and not the mean waves, like the apparatus used by Mr. Field. There are really two sets of apparatus here. One is suitable for working on voltages up to 15,000 with no earth connection, the record being made either on a falling plate or on a long length of film up to about 160 feet where many consecutive wave-forms are required. The other apparatus is for short lengths of film only. Mr. Duddell.

With regard to method No. 3, the extra power required to drive the alternator, Mr. Minshall was, I think, a little inclined to advocate this method. I regret that he has done so, for I totally disagree with him. I have never been able to find any basis for hoping for accuracy from this method. The efficiency of the alternator is totally changed by the action of the capacity current. With ordinary alternators, as I hope to show you presently on the screen, the capacity may produce serious resonances of the higher harmonics, and the effect of adding the capacity current will tend to excite the alternator, and will alter the efficiency by altering the distribution of losses. I see no means of getting over this objection. In fact, sometimes an alternator seems to take less power to drive it if the cables are connected, but most alternators seem to take very much greater power, the iron losses being increased by the high frequency of the capacity current.

Turning to Table No. 4 of Messrs. Constable and Fawssett's paper, they give the results of the tests of five different cables; by taking means of their figures their results may be resumed as follows:—

Cable No.	4	power-factor	2·2 per cent.
„	7	„	11·1 „
„	9	„	2·8 „
„	10	„	7·3 and 2·4 per cent.

This latter value, 2·4 per cent., was obtained with the choker in parallel, and is probably the more accurate, as the wattmeter was then working at a higher power-factor. For the last cable, No. 11, they give two totally different sets of results. The mean of the first set, obtained from curves E, F, G, is 1·4 per cent., and the mean of the second set, obtained from curves I, J, K, is no less than 8 per cent. I should like to ask them what is the difference between the tests E, F, G and I, J, K. In one case they say they obtained 1·4 per cent., and in the other 8 per cent. If you refer to the diagrams of the wave form, you will note that the first three, E, F, G, have a resonance of the fifth harmonic, and in the last three they got resonance in the third harmonic. How is it with the same cable they have these two different resonances? Did they use a different alternator in the two cases, or different frequency, or was there by any chance a transformer connected across the cable in the case of I, J, K? In no case do they give any indication as to the

Mr. Duddell nature of the machine and frequency used in each test. There is no doubt whatever that the self-induction connected between the terminals of the cable tests I, J, K was very much greater than in E, F, G, if the frequency was the same; yet they have accepted the high loss as more probably correct. Taking the figures for the five cables, which are not on the face of them doubtful, the losses, as Mr. Minshall said, are generally under 3 per cent., except in the one case of the No. 7 cable. That cable appears to be a bad cable as far as light-load loss is concerned.

I have tested by means of the wattmeter already mentioned various cables belonging to electric light companies in and around London, and in general the power-factor has varied from 1·5 per cent. to 3 per cent., the power-factor differing from one cable to the next, even when they were very similar in make and construction. I have also tried the effect of varying the voltage used on some cables over a fairly wide range, and find, as Messrs. Constable and Fawssett point out, that there seems to be a tendency for the power-factor to increase with increase of the applied potential difference. The effect of a change of the applied wave-form due to resonance of one of the harmonics has been to make the power-factor larger when the resonance occurred than when there was no resonance, evidently due to the increased value of the maximum instantaneous E.M.F. In all the tests I have so far made—and they have been made under ordinary working conditions, with the cables connected up to the switchboards exactly as used, and no allowance being made for any C^2R losses due to the capacity current—I have never come across a cable giving a power-factor above 3·5 per cent., except the No. 7 cable at Croydon, which I once tested, and I then had doubts as to the accuracy of my own test, as I stated at the time, as during the test there appeared to be such a violent resonance that I could distinctly hear the resistances in series with the volt coil of the Swinburne wattmeter I was using giving a brush discharge, though the R.M.S. voltage was only 2,000 volts. I still feel that this No. 7 cable should be further tested to find out the true cause of the great loss in it, whether it be real or apparent. Messrs. Constable and Fawssett suggest that it may be caused by a magnetic field, though this presents serious difficulties. I asked Mr. Fawssett to make some further experiments on this point, the results of which he will no doubt tell us. The noise in the telephone referred to may well be due to leakage from the outer to earth, and would increase with the load.

Messrs. Constable and Fawssett's paper strengthens the conclusion that it is quite possible to obtain commercially cables with a power-factor less than 3 per cent., and that therefore the danger pointed out in Mr. Mordey's paper of the large power schemes being crippled by the light-load losses in the cables themselves is not at all serious, and I would suggest that we may take warning from Croydon and avoid cables having such absurdly high losses as their No. 7. V.B. cable appears to have. Taking Messrs. Constable and Fawssett's tests of the No. 7 cable as correct at a 1½d. per unit, £50 per annum of the ratepayers' money is being wasted in warming the cable instead of a quarter that amount, and probably 1½d. per unit is an under-estimate

Mr. Duddell.

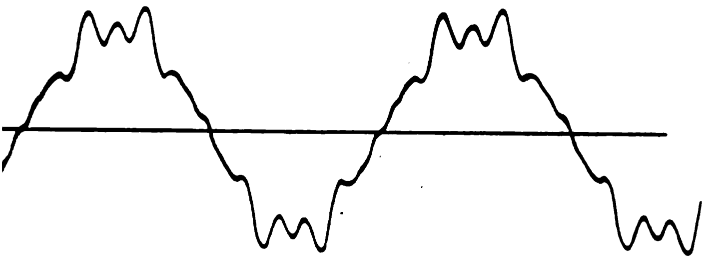


FIG. A.—Alternator on Open Circuit.

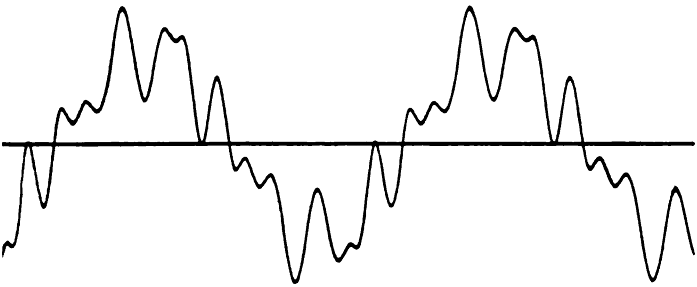


FIG. B.—Alternator and Cables, *Normal* Speed.

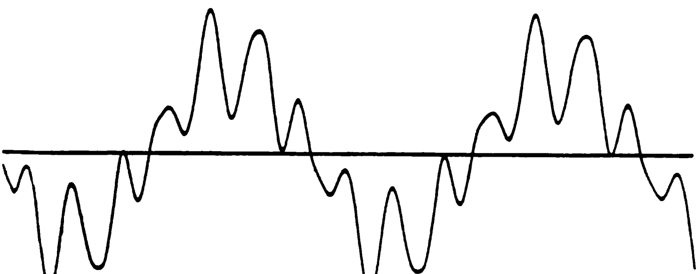


FIG. C.—Alternator and Cables, 8 per cent. *Over* Speed.

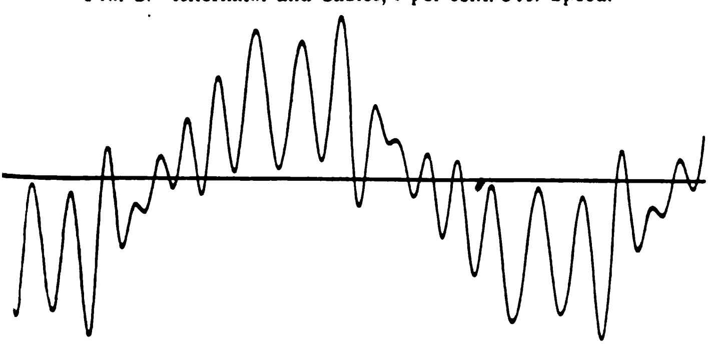


FIG. D.—Alternators and Cables, 26 per cent. *Under* Speed.
Scale: 1 mm. = 458 volts.

Mr. Duddell. of the cost of producing the power. With regard to No. 12 cable, which I believe includes most of these other cables, if you take the total losses, 901, you will find it is very little bigger than the 601 taken in No. 7, so that how it includes the high losses in No. 11 I do not understand.

Turning to Mr. Field's valuable paper on the resonance question, I do not think that he has laid sufficient stress on the dangers to the insulation due to these resonances of the higher harmonics.

Out of four large plants I have recently tested, three suffered seriously from resonances, and Mr. Field and Messrs. Constable and Fawssett show us that both Glasgow and Croydon do. These resonances not only strain unnecessarily the insulation of the cables; they also reduce the efficiency of the machines, make the regulation bad and the working of motors difficult.

Before proceeding I will define the term form factor as the ratio $\frac{\text{maximum instantaneous value}}{\text{R.M.S. value}}$ for any wave-form, a most useful factor which gives a measure of the strain on the insulation due to the wave-form.

I have to thank the Kensington and Knightsbridge Company for allowing me to show some resonances obtained on their circuits which will, I hope, exemplify the danger to insulation due to resonances. In each case the R.M.S. voltage is the same, viz., 5,000. Fig. A is the open circuit wave-form of the one of their alternators; the maximum volts are 1·45 times the R.M.S. volts, or in other words the form factor is 1·45, about the same as for a sine wave. Fig. B is the P.D. wave form of the same alternator with some cables connected which were on open circuit, the alternator running at normal speed; the form factor is 1·67. If, however, the speed of the alternator increases to only 8 per cent. above the normal, a resonance of the seventh harmonic occurs (Fig. C.) and the form factor increases to 1·74. On the other hand, if the machine is allowed to slow down to 26 per cent. under normal speed, a resonance of the fifteenth harmonic takes place (Fig. D), and the form factor rises to 1·94. This shows that, with a constant excitation, lowering the speed of the alternator may *increase* the strain on the insulation. A cable should never be energised by raising the speed of the alternator after exciting the latter, for fear of passing through dangerous resonances; the alternator should be run up to correct speed first, and then the excitation should be gradually raised.

In some other stations I have known the form factor to increase to as high as 2·2; thus, supposing 10,000 R.M.S. volts was applied to the cable, the maximum instantaneous voltage would be no less than 22,000 volts, or, due to the resonance, the cable would be strained with as high a maximum voltage as is given by a sine wave having a R.M.S. value of 15,500 volts, so that a cable designed to work at 10,000 volts on a sine wave might frequently be strained 55 per cent. in excess, due to a resonance of one of the upper harmonics. I think that cable makers have in some cases been unjustly blamed for failures due to resonance. These resonances are a frequent cause of the failure of E.S. voltmeters. It is to be noted that these high peaks on the P.D. wave mentioned do

Mr. Duddell.

not show on the station voltmeter which reads the R.M.S. value, so the engineer in charge has no idea how serious the strain on his apparatus is. It will be said that the ordinary rules of testing to twice the working pressure allows for the above strains. But this is not the case, as the whole of that margin and more is required to allow for the strains due to oscillations without its being reduced in any way due to resonances.

I have calculated the form factors for some of the wave forms in Messrs. Constable and Fawssett's paper :—

Curve A.	1·89	Curve E.	1·97	Curve I.	1·75
" B.	1·88	" F.	1·96	" J.	1·72
" C.	1·80	" G.	1·93	" K.	1·69
" D.	1·53			" L.	1·85

The difference between the form factors of curves E, F, G and of curves I, J, K, which are for the same cable, No. 11, show, as I have already mentioned, that the conditions under which these tests were made were evidently very different.

I think the above values, which are in no way exceptional, show

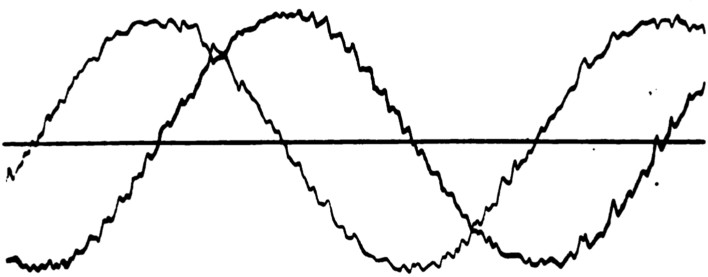


FIG. E.—Converter ; Effect of Sparking at Brushes on Direct-Current Side.

how very serious the dangers due to resonances of the higher harmonics are in practice.

Mr. Field has referred to ripples on the D.C. side of a rotary converter. I should like to draw attention to the irregularities which sparking at the brushes of a converter may produce in the P.D. wave-forms on the alternate-current side.

Fig. E shows the two P.D. waves of a small two-phase converter which was allowed to spark at the commutator.

The irregularities in both the P.D. waves due to this sparking are very marked. It seems to me that these high frequency ripples might easily be resonated and lead to very serious difficulties and dangers in working, so that a converter which was working perfectly satisfactorily might, by being allowed to spark at the brushes, cause a serious resonance with the attendant dangers to itself and the rest of the plant.

Prof. Hay.

Prof. A. HAY : In connection with Messrs. Constable and Fawssett's paper, I should like to make a few remarks with regard to the alleged

Prof. Hay. magnetic field which exists around the concentric cable. It is very difficult to believe that such a field can exist, and the only way in which it can possibly be brought about is by a slight excentricity in the inner conductor of the cable; a large amount of excentricity is of course out of the question. It seems to me that the experiments with telephones prove nothing at all, because there is a much simpler explanation, namely, a purely electrostatic disturbance. If you consider the outer conductor of the cable and suppose that it is conveying an alternating current, you will have a periodic rise and fall of potential at each end of the cable. You have your pilot wire in the same trough near the outer conductor, and you are bound to get a considerable amount of electrostatic action between the pilot wire and the outer conductor of the concentric cable. Such disturbances are well known to telephone engineers, and I think that there is no doubt the effects observed are due entirely to purely electrostatic causes and not to electro-magnetic disturbances, as has been suggested by the authors. In connection with the remarks made by Mr. Duddell, I am sorry to note that he is introducing a new term and using an old name for it. He speaks of the form factor of the wave-form. As a matter of history, I believe I am right in saying that Dr. Fleming was the first to introduce certain terms which had definite reference to the wave-forms of alternating currents and P.D.s. The two terms introduced by him were the *form factor*, which he defined as the ratio of the R.M.S. to the mean value of the wave, and the *amplitude factor*, which denoted the ratio of the R.M.S. to the maximum value. Dr. Fleming's amplitude factor is thus the reciprocal of Mr. Duddell's form factor, and Dr, Fleming's form factor is something totally different. As the term form factor has been used by both English and continental writers in the meaning given to it by Dr. Fleming, I hope Mr. Duddell will try and invent some other suitable term for the ratio of the maximum to the R.M.S. value.

Referring next to Mr. Field's paper, I wish to point out that from equation (9) and the further condition $K = \frac{4}{r^2}$ it clearly does *not* follow that the arrangement of branched circuit indicated will be equivalent to a simple non-inductive resistance of r ohms for *all* frequencies, since the equation (9) involves the frequency.

[*Note added later.* On investigating the matter fully, I find that balance for all frequencies may be obtained by making $K = \frac{4}{r^2}$, and that this is the *sole* condition required; Mr. Field's equation (9) is not a necessary condition. Thus Mr. Field's final result is correct, although his manner of arriving at it is entirely erroneous.]

I must further tax Mr. Field with using terms which are out of date. He speaks of ohmic resistance. I should like to ask Mr. Field whether there is such a thing as a resistance which is not ohmic. Then he speaks of the secohm. I should like to know what the secohm is. It is to be regretted that Mr. Field does not see fit to use the modern unit of self-inductance—the *henry*. Again, Mr. Field uses the term "self-induction" in two totally different senses. I should like to suggest the use of the term "leakage self-inductance," and then nobody can possibly

make a mistake; the matter is perfectly clear. If you define self-induction in one way and then proceed to use it in a totally different sense, confusion is bound to result. Prof. Hay.

In Part 2 of the paper Mr. Field states that he is perfectly aware that the peculiar effects obtained during the charging of a condenser are treated mathematically in the various text-books on the subject, implying that the subject had not been dealt with experimentally before. If Mr. Field is interested in the subject, I can give him references to several papers in which curves similar to those he gives are plotted to scale, showing not only the oscillations of the charging current of the condenser, but also the abnormal rises of potential which are produced.

[*Note added later.* The references are:—*Phil. Mag.* for 1892 (vol. xxxiv., p. 389); *Proc. Roy. Soc.* for 1893 (vol. 54, p. 7); *The Electrician* for 1895 (vol. xxxv., p. 840.]

In connection with the higher harmonics of alternating E.M.F. waves, it may be interesting to refer to an arrangement—recently patented by Arnold, Bragstad, and la Cour—in which the property possessed by the third harmonic in a three-phase system is utilised. It is not difficult to show that there can be no third harmonic in the P.D. wave between any two wires of a three-phase system supplied by a star-connected three-phaser; for, since a phase-displacement of ⅓ period for the main wave corresponds to a phase-displacement of a whole period for the third harmonic, the E.M.F.s corresponding to this harmonic will at every instant be equal and all act either towards or else away from the neutral point. But if the neutral points of generator and motor or transformer (star-connected) be connected through a lamp or motor load, a path will be provided for the high-frequency current corresponding to the third harmonic. Such an arrangement, originally proposed by Bedell, would, however, be practically useless on account of the choking effect of the motor or transformer circuits. Arnold and his co-workers overcome the difficulty by distributing the winding corresponding to each phase over two cores, the connections being such that while for the low-frequency three-phase currents the action remains unaltered, for the high-frequency current the motor or transformer coils are non-inductive. In order to obtain complete control over the high-frequency single-phase E.M.F., the inventors use a stationary armature, in whose core are embedded the conductors of the three-phase winding, but the fly-wheel magnet carries a double set of pole-pieces, one corresponding to the low-frequency three-phase E.M.F., and the other—thrice as numerous—giving rise to the single-phase E.M.F. of thrice the frequency. The advantages of low frequency for power work and of high frequency for lighting are combined in this *polycyclic* system, as it is termed by its inventors. A considerable saving of copper is claimed for it, in addition to its other advantages.

Mr. M. B. Field: In common with the previous speakers I attach great importance to the subject of dielectric hysteresis. I think that in all probability it may be intimately connected with the breakdown voltage an insulating material will stand. What I mean is this: if one Mr. Field.

Mr. Field. takes a number of similar slabs of a given dielectric and tests them up to the breakdown point it would probably be found that, other things being equal, that sample will break down first which has the greatest dielectric loss, and I would go further, and say that in any individual sample, provided the electric strain is uniform over the surface, it will probably break down at that spot where the dielectric loss is a maximum. If this be correct it gives us a very good reason for examining minutely this question of dielectric hysteresis quite apart from the cost of the lost power thereby engendered.

Before touching on that point, however, I would like to call attention to the fact that the losses to which Messrs. Fawssett and Constable particularly refer are not wholly confined to the dielectric; a portion, a very small portion it's true, occurs in the copper itself, so that a cable on open circuit which is insulated with a perfect dielectric will always have a power-factor somewhat greater than zero due to the C^2R loss in the copper core which the charging current gives rise to. If C be the charging current, or that flowing into the near end of the cable, and R is the total resistance of the "go and return" conductors, the copper loss will be $\frac{C^2R}{3}$. The apparent power is V C, hence the power-factor is—

$$\frac{C\,R}{3\,V}$$

or writing C as $2\,\pi\,n\,K\,V$, n being the frequency and K the total capacity in farads, we may say roughly that—

$$\text{P.F.} = 2\,n\,K\,R.$$

This shows us that the p.f. is proportional to the square of the length of the cable and to the frequency.

Now with ordinary lengths of cables at ordinary frequencies this power factor is extremely small, *e.g.* taking 10 miles of No. 7 cable we should get—

$$\text{P.F.} = 2 \times 60 \times 8{\cdot}36 \times 8{\cdot}8 \times 10^{-6} = {\cdot}0088.$$

This of course is a very small p.f., but if a thirteenth harmonic were present in the wave-form, the p.f. relative to this one harmonic would be over ·11 or practically as great as that noted for Cable 7 in Table IV.

The above rough approximation can of course not be applied for very long cables. In that case we should have to express the p.f. in the following way:

$$\text{If } V = V_0 \sin k\,t$$
$$C = C_0 \sin (k\,t + \eta)$$

at the near end of the cable, then η may be split up into three components, $\eta = \phi + \theta + \phi_1$.

The values of ϕ and θ are given in my paper on page 689, while ϕ_1 is such that—

$$\tan \phi_1 = \frac{\epsilon^{-2al} \sin 2\,a\,l}{1 - \epsilon^{-2al} \cos 2\,a\,l}$$

Now if we assume the resistance of the copper is vanishingly small $\theta = o$ and $\phi + \phi_1 = \frac{\pi}{2}$, which shows us that in this case only can

the power factor be zero. Having now disposed of that component of the loss which occurs in the copper itself, we must look to the dielectric as the seat of the greater proportion of the total loss. Mr. Field.

It is very striking that this dielectric loss can amount to more than one-third of the total C^2R loss in the H.T. cables, for this is what Messrs. Constable and Fawssett tell us.

Towards the end of the first volume of Maxwell the case of a stratified dielectric is mathematically considered, in which different values of conductivity and specific inductive capacity are assumed for the different layers and the phenomena of electric absorption and residual discharge are explained on that hypothesis. We then find the statement that the same reasoning applies and similar results are obtained if instead of assuming definite strata, we consider merely a conglomeration of particles with different constants as above. This is a very useful conception in connection with many manufacturers' insulating materials. Returning to the simpler conception of a stratified dielectric of which some of the strata act more or less as slightly conducting layers and take up little of the static strain, while others act more

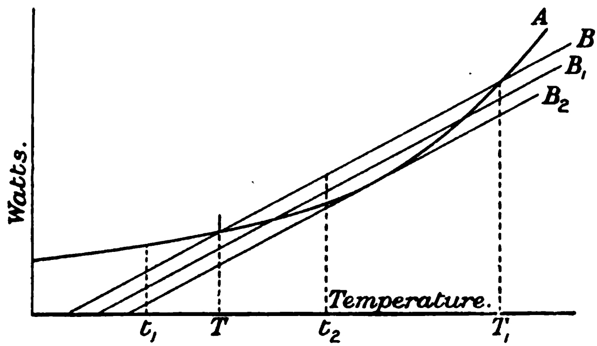


FIG. F.

A = watts generated per square inch of surface due to given voltage at given frequency; B B_1 B_2 = watts dissipated (with different temperature of surroundings).

truly as the dielectric medium in say an air or mica condenser, we see that we could consider a section of the insulation of the cable say between the inner and outer conductors as a succession of capacities and high resistances in series. Testing such a combination with a continuous current, it is clear that the insulation resistance might be very high, since the good layers would take up the static strain. Testing with an alternating current, however, one might find considerable loss and heating owing to the capacity currents flowing through the bad or semi-conducting layers.

In this case the loss would be proportional to the square of the voltage and to the square of the frequency, while the power-factor would be proportional to the frequency.

I notice in Table V. the approximate loss in a paper cable is shown a

Field. proportional to the square of the voltage, and I would like to ask how this table was derived, whether it rests on experiment or theory.

I said just now that it was probable the " breakdown " strength of an insulating material was closely related to the dielectric loss, and I would like to explain what I mean.

If we place a uniform slab of some dielectric compound between two metal plates so as to form a condenser, apply an alternating voltage, and measure the loss per unit area of surface at different temperatures of the dielectric, we find that after a certain temperature is reached, the loss increases at a very rapid rate. Now the rate at which the heat can get away from the slab naturally depends on a large number of circumstances, but principally upon the difference of temperature between the slab itself and the surroundings. Superimposing the two curves of watts generated (due to a given alternating voltage at given frequency) and watts which can be dissipated (by conduction, radiation, etc.) per square c.m. of surface, we get curves such as A and B in the figure above. At the temperature t_1 the heat generated is greater than that got rid of, so the temperature of the material would tend to rise. At the temperature t_2, on the other hand, the energy which the slab can get rid of per second is greater than that generated, hence there will be a tendency for the material to fall. T will therefore be a temperature at which the material will eventually arrive, since at this temperature the rate of generation of heat is equal to the rate of dissipation. Should however the temperature of the slab by any means rise above T_1, it might be said to be in an unstable state, for the temperature would then continually increase until the insulating properties of the material were destroyed by charring. The effect of increasing the temperature of the surroundings will be to materially raise the final temperature T to which the material will rise, for in this case the curve representing watts dissipated will be B_1 instead of B. Again, if we increase the surrounding temperature still further, we find that there will be no final temperature at all, but that the slab will get hotter and hotter until it chars. If now there is a spot in the slab which is weaker than elsewhere, more heat per unit area will be generated here, and the temperature will rise locally at this point. In fact, it seems possible for the temperature to rise at a weak spot to such a limit that actual scorching occurs there without the rest of the material being damaged. As soon as this occurs the insulation breaks down, an arc follows, and in all probability destroys all traces of the gradual burning which has preceded. In corroboration of this theory, which was verbally explained to me by Mr. Miles Walker after he had conducted a number of experiments in this direction, I would instance the following facts.

1st. The voltage that many materials, such as paper, prepared linen, presspahn, etc., will stand depends in some way inversely as the time of application. For example, a layer of paper will often withstand 15,000 volts for an instant, when it will not stand 5,000 continuously.

2nd. If slabs be tested as above described, and the voltage be applied for gradually increasing periods of time, and if they are examined after each application, it will often be found that scorching has occurred at some point without actually brea ing down, and if the material be

again tested under electric pressure it will finally break down at this point. Mr. Field.

3rd. In testing insulating tubes, etc., it is quite a usual practice to put a number under a high voltage test for a few minutes and then to feel them. The hot ones are cast aside as bad, since it has been found by experience that these would in the long run give out.

4th. Those materials which do not change their composition when subjected to a high temperature are usually found to be the best insulators, *e.g.*, mica, porcelain, glass, ambroin, and even air. Should the above theory be correct, we see that it will lead us to the important conclusion that the breakdown strength depends also on the frequency, and a material which easily burns would be much stronger if tested with continuous voltage than with an alternating. We further see that inflammable materials will have two strengths entirely different, one in withstanding mechanical piercing due to a strain of very short duration where the heating effect cannot come into play, and the other in withstanding prolonged strains. It seems probable that air and certain other insulators only break down through piercing, *i.e.*, in the first-mentioned manner.

To my mind a careful investigation into this whole matter would be of the greatest practical importance to the designers of electrical machinery.

Mr. W. M. Mordey: Mr. Constable and Mr. Fawssett deal with the distribution losses in the very practical form of a detailed examination of the actual losses in the Croydon system. Although we have at this Institution often discussed the subject of lost units, I do not think it has ever been put before us in so telling and complete a way. It is saddening to think that after all the efforts of the last twenty years the losses in a well-considered distribution system should be 22 per cent. of the energy sent out of the generating station. Mr. Mordey.

Such a paper shows clearly the direction in which we must work if we desire to reduce the distribution losses. Some of the losses can only be reduced by an outlay which would be unsound commercially, but some may perhaps be lessened.

The authors treat only of distribution losses. When they have exhausted that subject they may turn their attention to the inside of the station, when they will find there is a loss of coal of about 50 per cent. which, on paper at any rate, is capable of being saved. Then they may study the loss of about 85 per cent. in converting the heat energy of the coal into mechanical energy in the boiler and engine; and when they have studied those few small losses they may continue their investigations and consider the loss of more than 99 per cent. in the incandescent lamp itself between the heat energy given to the lamp and the light energy given out.

You will find, sir, that we shall not exhaust this subject to-night!

Before going on to the matter that interests me a good deal, that of the losses in the dielectric, I would like to refer to the question of switching transformers off, mentioned by the authors at page 723. It is generally believed that for economical working it is necessary to keep transformers as nearly fully loaded as possible—this is

Mr. Mordey.

not by any means the case. There is often no advantage in switching transformers off; there may even be a disadvantage in doing so. The efficiency curve of a good transformer is square-shouldered; it goes up quickly, to practically full efficiency, and then keeps nearly straight up to full load, often indeed falling a little as full load approaches. Now with such conditions two half-loaded transformers are as efficient as one fully loaded; if the curve drops a little, the two will be even more efficient.

For transformers having efficiency curves which reach practically full value at one-third load, three of them, each one-third loaded, will be as efficient as one fully loaded. Under such conditions it is best not to keep transformers fully loaded; it does not save energy, and it is bad for the transformers. If a given amount of energy is to be wasted, it is better to spread it over a number of transformers than to concentrate it in one—better for the transformers, and it lowers the copper loss.

Turning now to the question of losses in the dielectric of the cable, I quite agree with the authors in disliking the term. If the last speaker —who seems to have a liking for correctness in terms—could invent some term which is less cumbrous and more like Anglo-Saxon than "dielectric hysteresis," we should all be very grateful to him.

The paper that I read here some time ago on that subject has been referred to by the authors and by one or two speakers. I was rather badly treated in that discussion; it was apparently felt that in suggesting we had overlooked a serious cause of loss of energy, I had committed a crime of the most heinous character! But time brings its revenges. As the authors say, the subject was not exhausted then, and I am very glad indeed they have contributed to its further elucidation. There is a good deal to be done before we have got to the bottom of that subject. But it is one that we must consider. If there is a possibility of power-factors of anything like the order I mentioned in my paper—now confirmed by the present authors—or, I will go further and say that if there are power-factors of a much lower order—such as Mr. Duddell says he is satisfied do commonly exist—it is a matter of real engineering importance, especially for long distance high-pressure work. We must try and find some simple way of measuring these losses. The authors and Mr. Duddell—an investigator who should be carefully cherished—have used certain methods which are probably the best now available, but we want something more direct. I would suggest calorimetric methods. Direct measurement of the rise of temperature is of course hardly practicable. Under ordinary conditions even a serious loss of energy would not cause any noticeable rise of temperature in a cable.

It ought, however, to be possible to put a cable into a heat-insulated bath of oil or water and to run it and observe the rise of temperature that takes place when it is subject to high electromotive forces. It should then be possible to get the same rise and therefore the same loss by sending a direct current through the conductor of the cable and so measure the direct current energy easily. I do not say there are no difficulties. To what extent the losses are eddy-current losses is a matter to which attention must

be given. But I think there are ways of making calorimetric tests under conditions where, if eddy-current losses exist, they may be kept so small as to be negligible, or, in any case, their amount can be measured. This latter might be done by determining the loss, other than that due to resistance and current, by sending a low-tension alternate current through a cable in the calorimeter; under these conditions there would be no dielectric loss. Mr. Morley.

When I read a paper on Capacity Effects before this Institution, the discussion was associated with a good deal of heat other than what is usually measured by a thermometer. I hope we shall now discuss it calmly and find out seriously whether it is a loss which engineers—makers or users of cables—need consider. It is far more important to be sure that there is a small dielectric loss than that the copper has a high conductivity. If it is necessary to specify the latter carefully, much more important is it to consider a cause of loss which may be hundreds of times greater than that caused by the copper being 0·96 instead of 0·98 of Matthiessen's standard of conductivity.

May I be allowed to give as an example a few figures to show that this matter is of real importance even with small power-factors? It is not denied, I think, that there may be such power-factors as 0·1, but let us take the lower values of 0·025 or 0·03 which Mr. Duddell's experiments lead him to say need not be exceeded in any good cable. I do not, however, agree with him that with such values the matter is of no importance; even a 0·01 power-factor may be of importance. Let us take a case which may easily occur in practice. Assume a 10,000-volt three-phase cable for a transmission system supplying such an area as many power schemes are now proposing to deal with. Assume it has a capacity of 0·3 microfarad per mile, and a power-factor of 0·03—then the loss would be 7,400 units a year for every mile of cable, or about equal to an 8-c.p. lamp, always alight, for every 63 yards of cable. Assume this cable is ten miles long and is supplying a small town having an ordinary 12 per cent. load-factor and a "maximum demand" of 300 kw.—the ordinary "authorised distributor" of the power bills—then the dielectric loss in the cable will be 23·4 per cent. of the energy delivered, or as much (in percentage) as the authors show is lost in the whole system at Croydon in transmission and distribution.

If this is true, the question deserves serious attention.

It would be interesting—in these days of power bills and long-distance high-pressure schemes—to follow this point a little further, but I will only point out that if the copper loss in this cable is 5 per cent., and if the "authorised distributor" loses only 20 per cent. in distribution, then the generating station must send into that cable about 48·5 per cent. more energy than ever reaches the customers. One point, however, must not be lost sight of: the dielectric loss, whatever it may be, does not greatly increase with the size of the cable; thus it will be relatively less serious on a cable for a large load than for a small one. For the latter it may be serious enough to prevent the economical supply of small towns through long underground cables, and may strongly support the demand for bare overhead conductors.

One other point—this loss is not a capacity loss at all, but a kind of

Mr. Mordey.

resistance loss having a unity power-factor of its own ; it would take place just the same if the cable had no evident capacity.

The President announced that the scrutineers reported the following candidates to have been duly elected :—

Members.

Ovide F. Domon.
Giovanni Giorgi.
Wyndham Monson Madden.

Associate Members.

Frank Anslow.
Robert Malcolm Campbell.
Johan Denis Carlmark.
John Mathieson Keenan.
Walter Henry Le Grand.
John F. Magoris.
John Frederick Pierce.
Theodore Rich.
Harold Stokes.

Associates.

Arthur Chester.
Edward Alan Christian.
Wm. Frederick Coaker.
Wm. Thomas Dalton.
Theodore J. Valentine Feilden.
Thos. Henry Flamwell.
John Walker Fyfe.
Chas. Ward Hammerton.
Hugh Henry McLeod.
Chas. Edward Harrison Perkins.
Louis Boniface Wilmot.
Clifford George Woodley.

Students.

Herbet Paul Amphlett.
William Bell Begg.
Eric Frank Cliff.
William Prescott Crooke.
Thomas Davies.
Henry T. Debenham.
Eustace Jonathan Down.
Henry Firth.
Charles Butler Grace.
Harry Lillywhite.
Joseph F. Mongiardino.
Leonard John Pumphrey.
Chas. Alexander Rainsford.
Roy Grosvenor Thomas.
Geo. Keenlyside Tweedy.
James L. Wilson.
Martin Julius Wolff.

The Three Hundred and Ninety-second Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, April 23, 1903—Mr. ROBERT K. GRAY, President, in the Chair.

The minutes of the Ordinary General Meeting held on March 26th, 1903, were taken as read and signed by the President.

The names of candidates for election into the Institution were taken as read, and ordered to be suspended in the usual form.

The following list of transfers was published as having been approved by the Council —

From the class of Associates to that of Members—

Walter Joseph Higley.

From the class of Foreign Members to that of Members—

Frederico Pescetto.

From the class of Associates to that of Associate Members—

Frederic Robert Bridger.	William Richard Kelsey.
Robert Marshall Carr.	Theodore Arnold Locke.
Robert Tyndall Haws.	Arnold Philip.
Francis C. Hounsfield.	Maurice Solomon.

T. B. Wright.

From the class of Students to that of Associate Members—

Frederic Chas. Kidman.	John Warrack.

From the class of Student to that of Associate—

Arthur John Cridge.	Alfred Eddington.

Messrs. H. Brazil and L. T. Healey were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. A. Heyland, H. A. Humphrey, E. and F. N. Spon; to the *Building Fund* from Messrs. B. G. Jones, H. T. Lines, A. Nield; and to the *Benevolent Fund* by Mr. S. E. Britton, to whom the thanks of the meeting were duly accorded.

The Secretary read the following nominations by the Council for the officers and Council for the ensuing Session :—

MEMBERS NOMINATED BY THE COUNCIL FOR OFFICE 1903–1904.

As President.

Nomination.	ROBERT KAYE GRAY.

As Vice-Presidents (4).

Remaining in Office.	JOHN GAVEY. Sir OLIVER LODGE, F.R.S.
New Nominations.	Dr. J. A. FLEMING, F.R.S. J. E. KINGSBURY.

Ordinary Members of Council (15).

Remaining in Office.	SIR JOHN WOLFE BARRY, K.C.B., F.R.S. S. DOBSON. BERNARD DRAKE. H. E. HARRISON. Lt.-Col. H. C. L. HOLDEN, R.A., F.R.S. The Hon. C. A. PARSONS, F.R.S. W. H. PATCHELL. J. H. RIDER. A. A. CAMPBELL SWINTON.
New Nominations.	T. O. CALLENDAR. S. Z. DE FERRANTI. FRANK GILL. F. E. GRIPPER. G. MARCONI. W. M. MORDEY.

As Associate Members of Council (3).

Remaining in Office.	W. DUDDELL. SYDNEY MORSE.
New Nomination.	A. J. WALTER.

As Honorary Auditors.

For Re-Election.	F. C. DANVERS. SIDNEY SHARP.

As Honorary Treasurer.

For Re-Election.	ROBERT HAMMOND.

As Honorary Solicitors.

For Re-Election.	Messrs. WILSON, BRISTOWS & CARPMAEL.

The PRESIDENT: Before the discussion of the papers of Mr. Field and Messrs. Constable and Fawssett is opened, I desire to make a few remarks with regard to the recent visit to the North of Italy of about 120 members of the Institution. The object of these remarks is to place on record, in the Proceedings of the first meeting held since our return, the sense of gratitude felt by the Institution for the great kindness shown by our Italian hosts.

In addition to the many interesting visits which had been arranged, the very cordial reception given to the party was quite remarkable. Senator Colombo, who had been in Rome, made a point of coming to Milan to meet us. Professor Ascoli, the President of the Associazione Elettrotecnica Italiana, also came from Rome to preside at the banquet given in our honour by that body. Mr. Blathy, of Messrs. Ganz and Co., came specially from Buda-Pest to assist in showing us the Valtellina line, in the electrification of which his firm played a preponderant *rôle*. Mr. Cini, of the Adriatic Railway Company, who are interested in the Valtellina line, came from Florence. Our visit to the Tornavento Power Station, with the inspection of the electrified Milan-Varese line, was rendered more instructive and agreeable by the presence of Mr. Kossuth, one of the Directors of the Mediterranean Railway Company, and of Monsieur Lagout, of the Thomson-Houston Company de la Mediterranée, who came from Paris with the object of accompanying us and showing us the work of his firm. Senator Colombo and his friends showed us the large water-power station, at Paderno, of the Italian Edison Company, and also their Distributing Stations in Milan. Senator De-Angeli conducted us to the Vizzola Water-Power Station of the Societa Lombarda per Distribuzione di Energia Elettrica. In addition to these, the Chairman of the Milan section of the Associazione Italiana Elettrotecnica, Mr. Bertini, and the Secretary—Mr. Semenza—had, through the courtesy of the proprietors, enabled us to visit several works in the neighbourhood of Milan and in Milan itself which proved of great interest to the visitors. It is impossible to thank Mr. Semenza too much for the enormous labour he must have gone through to provide for the entertainment of a numerous body. The Council will in due course tender the thanks of the Institution to our late hosts in a more formal manner.

Before terminating I think I should inform the members of the Institution that the visit to the North of Italy is considered by all who took part in it as a very successful one, and that Dr. Silvanus Thompson, who had taken so much trouble in initiating it, Mr. Hammond, the reporter of the Foreign Visits Committee, and our Secretary—Mr. McMillan—who so successfully carried out all the details of the expedition, certainly earned the praise which they received from all sides.

With these remarks I shall now call upon Professor Carus-Wilson to open the adjourned discussion on the papers read by Mr. Field and by Messrs. Constable and Fawssett.

RESUMED DISCUSSION ON PAPERS ON "DISTRIBUTION LAWS IN ELECTRIC SUPPLY SYSTEMS," BY A. D. CONSTABLE, A.M.I.E.E., AND E. FAWSSETT, A.I.E.E., AND "A STUDY OF THE PHENOMENON OF RESONANCE IN ELECTRIC CIRCUITS BY THE AID OF OSCILLOGRAMS," BY M. B. FIELD, M.I.E.E., A.M.I.C.E.

Prof. Carus-Wilson.

Professor C. A. CARUS-WILSON : Mr. Field has brought before us a subject of great importance and interest, and has illustrated his paper by showing us some interesting slides. Mr. Duddell has supplemented what Mr. Field has given us by further illustrations of resonance in transmission circuits, and the jagged, saw-like curves which he showed were calculated to alarm us, especially when accompanied by statements that they involved very high voltage. The question I want to raise to-night is whether the effects that have been shown to us are really serious, in view of the actual strains to which high-tension circuits are subject in every-day working. Mr. Field in his paper rightly alludes to what has been written on this subject in the United States, and draws attention to the communications that from time to time have appeared on this subject in the transactions of the American Institute of Electrical Engineers. I quite agree with him in thinking that those transactions are not as well read on this side as they should be, and I am also surprised that more members of our own Institution are not members of the American Institution. I notice, however, that his paper gives us several results which have already been arrived at by other workers. For instance, the equations he gives us at the bottom of p. 685, for the induced pressure due to sudden and rapid oscillating effects consequent upon breaking a circuit with a load on, are the same as those given by Mr. Steinmetz two years ago, though arrived at by a different process. On p. 691 the equations that Mr. Field gets for the rise of pressure, due to resonance, at the end of the long transmission line, appear to me to be identical in result, with some slight exceptions, to which I will refer later, with those given by Houston and Kennelly in 1895. I refer to these facts simply to point out that Mr. Field has arrived at the same results by working out these problems on independent lines from his own standpoint, in a way quite different from what others have done. On p. 691 Mr. Field gives the fundamental conditions for resonance, and an equation for the rise of voltage at the end of a long transmission line. I do not see why he needs such a confusion of terms at the bottom of p. 688, where he introduces Greek letters as well as Roman letters; I have not quite been able to follow him in that. Surely it is simpler to express the condition of maximum resonance by the expression—

$$l = \frac{\pi}{\sqrt{2}} \frac{1}{\sqrt{(\omega \kappa \mathrm{l} + \omega^2 \kappa \lambda)}}$$

In the way Mr. Field gives it we have to look back to a complicated series of equations in order to understand it. [*Communicated.* After hearing Mr. Field's explanation of his symbols I admit that his equations are quite as simple as the one I have given above.] I should like to show on the blackboard what this distance l really is. If A is the receiving end and B the sending end, then the pressure is a maximum

Prof. Carus-Wilson.

of V_1 volts at A, and as we get nearer the sending end the pressure drops to a minimum of V_0 volts, and rises again if the line is long enough. The length l between the positions of maximum and minimum pressure is given by the above equation. In practice this distance is very

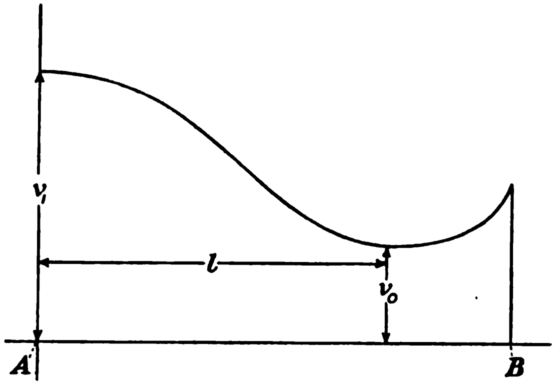


FIG. G.

great. In a case which I had occasion to work out recently for a three-phase transmission line about 100 miles in length, this distance came out to 1,430 miles, that is to say, in order to get the maximum resonance effect the line would have to be 1,430 miles long, whereas the line was only 100 miles long. Consequently the actual rise of voltage due to resonance was a mere nothing. In the next equation Mr. Field gives us an expression for the relation between V_0 and V_1, from which we can find the rise of pressure due to resonance. I cannot help thinking that Mr. Field or his printer has made a slip in that equation; he has in the denominator—

$$- 2 \epsilon^{- \pi \tan \theta}$$

I think that should be—

$$+ 2 \epsilon^{- \pi \tan \theta}$$

for then that rather complicated equation becomes simply—

$$\frac{V_0}{V_1} = \cosh l a$$

That is the usual form of the expression for this ratio, where l is the length in miles and a is the quantity depending on κ, λ, and n.

In the case of the long transmission line to which I referred, taking L at 100 miles, the total rise in voltage did not amount to more than 2 per cent., that is to say, not only is the line required to get the maximum resonance effect of great length, far beyond anything that we get in practice, but the actual rise is quite insignificant. I think it is now generally recognised that resonance effects in long distance transmissions are really of no importance. When we get the frequencies of the higher harmonics that Mr. Field's paper deals with, we get reson-

Prof. Carus-Wilson. ance effects, but they are so small, on account of the very small amplitude of the waves that are magnified, that the increase in pressure above the normal voltage is a very small percentage when you compare peak with peak or mean with mean. I take it, then, that in actual practice these resonant effects are extremely small in long-distance transmissions, even when you take account of the higher harmonics. But not only that, the effects of resonance, to which allusion has been made by Mr. Field and Mr. Duddell, are altogether insignificant when you come to consider the strains that are actually put upon high-tension transmission apparatus by oscillating discharges. I notice that Mr. Field refers to all the effects dealt with in his paper as resonance effects. I have always understood that the term resonance referred to a stationary wave, the kind of thing shown in the diagram, which is a permanent condition of affairs. That was the meaning of the term adopted by the people who introduced the expression; but in this paper, and in other places also, resonance has come to be applied to a great many other effects accompanying high tension; for instance, oscillatory effects. I quite think that those are the phenomena we have to fear in a transmission circuit, but they are not resonance effects at all, since they are not due to stationary waves—they are due entirely to momentary changes in the conditions of loading the line. These are the really important effects to be considered, since they subject transmission lines to enormous tensions, far greater than any due to resonance. It would be a good thing if we could get some more tests made on these oscillatory effects. The equation for V on page 685 of Mr. Field's paper gives the pressure caused by suddenly breaking a circuit with a load on. The term $\sqrt{\left(V_1^2 + C_1^2 \frac{L}{K}\right)}$ indicates the degree of strain that is put upon the insulating material, from which it appears that the strain upon the insulating apparatus depends upon the load, and is proportional to the current that is being broken, and that if the circuit could be broken when $C = O$ there would be no rise of pressure. This is entirely borne out by tests made on some long-distance transmission lines in the United States, when it was found that the high voltage induced by breaking the circuit was entirely a question of the load that happened to be on the circuit at the instant of the break. When the load was broken under oil, the effect of the break, as shown by means of an oscillograph, was like this:—

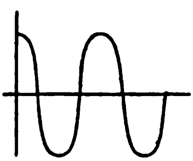


FIG. H.

There is an oscillating discharge extending for a few waves, and then the oil breaks the circuit at the zero point. If it were not for the fact that an oil switch breaks the circuit at zero point, I think it would not be too much to say that high-tension long-distance transmissions carrying very large currents would be impossible. But it is found in practice that the effect of oil is to allow the arc to spring just for a short time, extending over about half a dozen waves, and then to break the circuit at the zero point, that is to say, in a remarkable way the oil switch does exactly what we should want it to do, and breaks the circuit at the moment when the current is nothing, thereby enabling the circuit to be

broken without any rise of pressure. In the tests I referred to, currents of 30 amperes at 40,000 volts were broken by an oil switch without any rise in the voltage being shown on the oscillograph. The danger of breaking a high-tension circuit may thus be less than that of making the circuit, for I do not know of any switch by which the high voltage that you get when making a transmission circuit can be prevented, unless, of course, rheostats are used. It would appear, then, that transmission circuits may be subject in ordinary working to very high pressures due to oscillatory discharges altogether out of proportion to the effects due to resonance, twice, or even three times, that of the normal voltage. I therefore endorse what Mr. Field says at the end of his paper that the oscillatory effects are those that need most to be studied by means of the apparatus we have at hand, notably the oscillograph. Prof. Carus-Wilson.

(*Communicated*): In criticising Mr. Field's equation on page 691, I was under the impression that he was using the terms involving the resistance, self-induction, and capacity as vector quantities, in which case the expression for the ratio of the squares of the pressures at the two ends of a transmission line on open circuit is of the form

$$\tfrac{1}{2}(\cosh 2\,R\,l + 1),$$

R being a constant involving the capacity, etc., and l the length of the line. I see now, however, that he is not using vectors but numerical quantities, in which case the expression is of the form

$$\tfrac{1}{2}(\cosh 2\,P\,l + \cos 2\,Q\,l).$$

$Q\,l$ is the angle of advance in phase of the pressure as the sending end is approached; for maximum resonance this angle is $\frac{\pi}{2}$, so that this expression then becomes

$$\tfrac{1}{2}(\cosh 2\,P\,l - 1),$$

and this is the equation given by Mr. Field, putting cosh for the more complicated exponential terms used in his paper, the sign being rightly negative.

Mr. G. L. ADDENBROOKE: My remarks will bear upon rather a different part of the subject to that alluded to by the last speakers. The paper covers so much ground that it is impossible to deal with all the points in it. As I have had considerable experience in testing cables for what is called dielectric hysteresis, perhaps some account of what I have done might be interesting. My own work began in the following way. Dr. Muirhead some two years ago lent me some of his special condensers for the purpose of investigating the losses which took place in them. I had been too busy to do anything with them up to the date of Mr. Mordey's Institution paper two years ago, but startled by his results I forthwith began some tentative experiments which I mentioned in the debate. Shortly after, I received a communication from the Henley Telegraph Cable Co., who were concerned from a commercial standpoint, and who were rather upset by the possibility of this Mr. Addenbrooke.

Mr. Addenbrooke. large dielectric hysteresis loss. The result was that they asked me to make some investigations at their works on the subject. The first question which arose was, how these experiments should be made. That really, I think, is the matter which is before us at the present moment, because it is not much good having experiments made until we are pretty certain that the means used for making the experiments are likely to give fairly correct results. I therefore went into this matter. My idea was to employ the electrostatic system of measurement, which I described generally at the International Congress at Paris two and a half years ago. When I came to look into it, it seemed that it would be suitable, and also that it was adapted to meet the following very important point. Going into the calculations with regard to air core transformers for insertion in the circuit, I found it usually meant that you must have three or four microfarads capacity in the cable, in order to keep your air core transformer within reasonable limits, which of course means a long length of cable, which it is very troublesome to deal with and is not very commercial. By using the electrostatic system, even as the system stood intended for ordinary work, I found one could go down to half microfarad with, it appeared to me, a fair chance of being pretty accurate. There is no doubt that by special arrangements it is possible to measure electrostatically the loss in very small capacities indeed—in fact, since the date of my experiments, in a paper in the *Journal of the American Institute of Electrical Engineers*, Mr. Miles Walker described how, by means of a special electrometer used in order that the high pressure might be directly applied to it, he has been able to make dielectric hysteresis measurements on slabs a foot or two square. Therefore it is clear that, apart from its suitability otherwise, the electrostatic system has very great advantages for the commercial measurement of dielectric hysteresis, because we can deal with very moderate lengths of cable.

My apparatus being set up at Messrs. Henley's, arrangements were made for carrying out tests from 2,000 up to about 6,000 volts, and I will give you a few specimens of them. About ·9 of a microfarad of unarmoured lead-covered concentric cable was tested between the inner and outer. I may say that the arrangements at Messrs. Henley's did not, unfortunately, permit of a constant periodicity in all tests being obtained, because they had to vary the speed of the alternator to some extent to get the different voltages, so that the experiments are not so comparable directly as they might have been, but when allowance is made for this they all come very close to each other. The results I got are given in Table I. It is to be noted that the power-factor gradually rose as the voltage rose. Another point that turned up in these experiments was that the results are all somewhat lower than those published by Mr. Mather, which were also conducted on paper cables, and which he mentioned in dealing with Mr. Mordey's paper. Of course there may be different sorts of paper, but as most cable makers deal with the same class of paper, I did not think the difference could altogether be accounted for that way. The question therefore arose whether the difference was due to differences of measurement or to the material. Of course, also, there might have been possible differences

due to the wave forms that were used in the experiments. Unfortunately, as regards this, I had not the means at my command at the time of ascertaining what these forms were, but I doubt if this can account for all the difference. However, while I was still considering this question some measurements had to be made at Wood Lane on a large inductive resistance which I designed for Messrs. Willans and Robinson for enabling alternators to be tested at proper power factors and which was specified to carry a certain current for six hours at 5,000 volts without undue heating. From the ordinary calculations on a resistance of this Mr. Addenbrooke.

TABLE I.

Cable Tests at W. T. Henley's Telegraph Works, Ltd.

Capacity ·9 mf. Unarmoured lead-covered C.C. Test between Outer and Inner.

Volts.	Amperes. Actual.	Amperes. Calculated.	Watts.	Periods.	Power Factor. Per cent.
2,040	·24	·33	5·1	28·7	1·04
2,000	·388	·536	10·4	48	1·34
3,000	·36	·486	18	29	1·67
3,000	·55	·7	24	41	1·46
4,000	·36	·452	26·7	20	1·86
4.040	·715	·965	47	43	1·63
5,700	·6	·755	60·4	23	1·72

TABLE II.

Cable Tests at Wood Lane.

Capacity. Unarmoured 3 Core. Tests between Cores A, B, C.

Volts.	Amperes. Actual.	Amperes. Calculated.	Watts.	Period.	Power Factor. per cent.
					Cores used.
5,000	1·11	·863	50	50	·9
2,500	·637	·432	18·5	50	1·10
2,500	·95	·69	32·5	50	1·37
5,050	1·68	1·38	102	50	1·2

Mr. Addenbrooke. sort, made for me by Mr. Berry of the British Electric Transformer Company, we came to the conclusion that the power factor, including the losses in the iron, ought to be about 4 per cent., and the instruments correctly indicated about 4 per cent. Therefore I think this is one fairly strong reason for saying that the instruments were capable of measuring power factors of this sort with close accuracy. In the case of Mr. Miller's cable, which is a three-phase cable, it was tested at 5,000 volts and 2,500 volts. When tested between one core and the other the hysteresis loss came out at about 1·2 per cent., and in one case as high as 1·37 per cent. Again, as in Table II., the results are comparable with the other results I obtained. This was a British Insulated Wire Company's cable of the same kind that Mr. Mather was experimenting with. Having arrived at this point, I thought I would check my working by testing with an air core transformer, that is to say, using the electrostatic system and putting an air core transformer in. For that purpose Mr. Savage, of Henley's, was good enough to have one constructed of flexible, of which they are makers. Dr. Fleming, in his book on electric testing, has put forward an air core transformer as an excellent means, which it undoubtedly is, of finding out whether a wattmeter indicates properly on low power factors because you can with it get a power factor as low as 3 per cent. Having this air core transformer, it occurred to me that I would test my own wattmeter with it. This I accordingly did at Messrs. Henley's before applying it to the cable. The result was that when I came to work out the experiment it appeared as if there was some loss in the air core transformer itself. In the debate on Mr. Mordey's paper it was taken as an axiom that there was no loss in the air core transformer. Not being certain about this, I got the air core transformer sent up to my own laboratory in Victoria Street, where I had the Deptford current. It was again tested at about double the periodicity at which it was tested at Messrs. Henley's. The result was that the loss went up somewhere about as the square, which it would do if that loss was due to eddy currents. I may say that in this case the loss was of the following character. The whole weight of the copper in the air core transformer was somewhere about one hundredweight, and the loss I got at 89 periods was about 36 watts, *i.e.*, about one-third of a watt per pound. When you come to consider the very large number of ampere turns there are on such a transformer, and what a very strong field there is, it does not seem impossible that there should be a loss of this sort. In my case, too, the flexible wire, which was of the ordinary character, happened to be very new. In Mr. Mather's case he used an air core transformer of solid No. 14 copper, as far as I understand. I see from calculations that during his tests he must have had 12,000 ampere turns on the coil, which makes a very strong field. It seems quite possible that he may have lost 50 or 60 or even more watts in 80 lbs. of copper, which deducted would make his results nearly the same as mine. I do not wish to cavil at Mr. Mather's figures. I think he did his experiments somewhat hurriedly, and that to have got as near as he did in the time was almost a feat, because it is a very difficult thing to get reliable experiments with this dielectric hysteresis work. Perhaps I may be allowed to put

Mr. Addenbrooke.

my results into ordinary figures, because I think it is very important we should recognise that, at any rate for practical purposes, the dielectric hysteresis loss in itself is not very serious. In the case of Mr. Miller's cable, which was a three-phase feeder, 2½ miles long, working at 5,000 volts, the actual loss was about 100 watts, or 40 watts per mile. I may say that that was tested without any load on, and therefore perhaps we had rather a bad curve, in fact, the main was actually tested afterwards by Mr. Duddell with the oscillograph, and the results were shown on the screen at the last meeting. Unfortunately I cannot say now which of Mr. Miller's cables the test was made on, but it may be of interest to know that one of Mr. Duddell's results is the wave with which my tests were made.

There are one or two general conclusions I should like to mention. On another occasion a fresh set of cables were put up for experiment. Unfortunately I was not there myself, but my assistant, Mr. Robinson, who really works my instruments better than I do myself, conducted them. In this case there was an iron sheath outside the cable, and the whole of the results came out higher than in other cases. As far as I know the cables were exactly the same; this bears out some results that have been given in the paper we are discussing. I was rather afraid to publish these particular results at the time, as my theoretical friend pulled a long face, but as the matter has been brought forward in another form, I mention that in that particular set of experiments we did get 30 or 40 per cent. increase in the loss when the cable was covered with an iron sheath. There is another general point which I think is worth bringing forward with regard to this dielectric hysteresis loss. These losses go up with the voltage to some extent; as a matter of fact the voltage on one occasion was carried out nearly as high as 11,000 volts, or as much as the cable would stand, with a view of seeing what would happen. The watt losses go up more than proportionally, so that if you keep the wattmeter on and watch it, it really forms a sort of guide to what is going on in the cable, and when you get near the breaking point you get a very great increase of the watt losses. I am inclined to think that a measurement of this class may be very useful in testing cables as to what they are likely to stand, in lieu of simply putting on a breakdown voltage, or say two or three times the working voltage. In testing a boiler, no one would think of testing it up to its breaking pressure, as to do this would cause permanent damage; and, in the same way, by putting too high a pressure on a cable its resisting powers may be permanently injured, but tests, at a few gradually increasing voltages, of the watt loss with an alternating current will enable a curve to be constructed from which the behaviour of the cable can be seen and the point beyond which it is undesirable to press the voltage can be predicted.

Mr. Sparks.

Mr. C. P. SPARKS: The two papers before us show how much we are indebted to Mr. Duddell for the oscillograph. I regret to have to say this, after so many other speakers have mentioned the matter, but as I have worked with him a good deal, I feel how much we are indebted to him for such an efficient instrument to attack some of the more obscure problems in connection with transmission work. Mr.

Mr. Sparks. Field's paper brings prominently before us the difference between the modern three-phase generators with an irregular wave form, and the old type of single-phase machines. In Mr. Field's paper, the author directs attention to the advisability of localising the characteristics of each system with the oscillograph. I cordially endorse his recommendation. Some three years ago, my attention was directed to the effect of running up an excited generator on mains of high capacity when it was found that as the frequency rose the current passing into the mains rose suddenly to a high value, and then fell with increasing pressure and frequency. This occurred twice before the working frequency and pressure were reached. The oscillograph at once showed what was happening. Some tests which Mr. Duddell carried out for me with the oscillograph, with the moving film, showed that all variations in the number of mains, generators, and, in our case, throw-up transformers should be made at standard frequency. Hence it is usually dangerous to energise a main by running up from a separate generator or motor-generator, unless the working frequency be reached before the alternator is excited. At the Deptford station, Mr. Partridge introduced ten years ago the method of energising the mains through a transformer, the secondary of which was gradually short circuited. Tests showed this method to be safe, so long as the resistance of the secondary did not fall below a critical value. The use of such an apparatus is generally limited to generators of the copper armature type, owing to the absence of harmonics, and this system cannot generally be applied to the present form of three-phase generators. The safest method to switch on a main is through a non-inductive water resistance, which is gradually cut out over a period of a quarter of a minute. Last year Mr. Duddell took records of switching on cables under these conditions, and it was found that as long as a period of something like a quarter of a minute was taken no undue rise of pressure occurred in switching on cables, the longest length being 14½ miles. The actual length tested was something like 8 miles.

The modern oil break switch efficiently disconnects the feeders under normal conditions of load. Mr. Duddell took records which showed that, as pointed out by a previous speaker, the current is apparently always broken at the zero point, and under all normal conditions the circuit was broken without any dangerous rise of pressure. The most dangerous operation is the removing of a short-circuited feeder, as in addition to the heavy current to be broken the frequency of the station may be affected. Up to now the only really safe condition to remove such a feeder is by keeping your frequency up, and reducing the pressure momentarily in order to disconnect the feeder.

Mr. Campbell. Mr. A. CAMPBELL: With regard to Mr. Field's method of testing whether his water resistance was non-inductive or not, I think he might have done so more easily by trying if at every moment the ordinates of the current curve had a constant ratio to those of the voltage curve. If this is not the case, the circuit is not non-inductive.

(*Communicated*): The simpler method would, however, give no indication of the value of the power-factor.

Mr. Duddell.

Mr. W. DUDDELL: Mr. Campbell has pointed out that the two curves should be exactly similar. Unfortunately, for watt meter measurements where considerable accuracy is required, an error of one minute of a degree is a serious matter in the lead or lag of the current through the resistance. One minute of a degree is $\frac{1}{60}$th of $\frac{1}{180}$th, or $\frac{1}{10800}$th of a half period. I do not think it is possible to plot a wave form with sufficient accuracy to show a lag or lead of that order. I am afraid some other method has to be used, such as employing a very high frequency in order to determine such small angles.

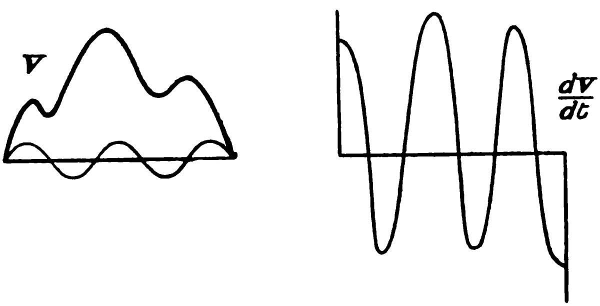
Dr. Thornton.

Dr. W. M. THORNTON (*communicated*): It is to be regretted that Mr. Field was unable to make observations at the generator end of the cables, or on the high-tension side in the sub-station. There can be little doubt, after comparing this and Messrs. Constable and Fawssett's paper, that the harmonics of Curve XV. are chiefly due to the capacity of the cables; but *resonance* is so violent and sudden a phenomenon that one is impelled to ask whether there may not be any other explanation.

As I understand the method of experimenting, the curves were taken from the low-tension side of a 175 k.w. transformer, unloaded. There is then entering the cables the charging current together with a small transformer current. But the secondary voltage of a transformer is proportional to the primary *current*, and therefore any disturbance of this by the distributed capacity of the cables will be inevitably felt on the secondary side, though the conditions may be far from resonance.

According to this view, the greater the capacity of the cables between generator and transformer, the greater would be the amplitude of the harmonics on the voltage wave observed on the low-tension side of the transformer.

The remarkable capacity currents caused by strong harmonics can be seen by drawing the rate of change of the voltage against the generated wave: this representing the current to a suitable scale.



The intensity of the harmonics depends very much on excitation, and one is led to ask whether the conditions of excitation were precisely the same in Curves XV., XVI., XVII., XIX. They are widely separated in time, and it is possible that all the conditions might not have been repeated, especially if the tests were made in the early morning on a very light load.

Dr. Thornton. With regard to the remark on page 655, that the field currents are not much disturbed by armature reaction, I have found that a variation of 5 per cent. is common in a separately excited three-phase bi-polar converter, and I should think that in a multi-polar machine on full load the effect would be even more marked on account of the relatively smaller time-constant of the windings.

Harmonics in the voltage wave, on reaching the undisturbed magnetic circuit of a converter, *will reproduce the magnetic conditions which started them*. And if the iron is not saturated, the disturbance so caused may be sufficient to increase the amplitude of the ripple in the continuous voltage. This would account for the large ripples recorded, and they should be larger the greater the angle of lag.*

On page 655 Mr. Field attributes the smoothing out of harmonics when two or more generators are in parallel to the increased inductance diminishing resonance. I made observations in the Wallsend power-house of the Newcastle Electric Supply Co. two years ago which led me then to believe that the obliteration of harmonics which was always noticed when several generators were in parallel, was really caused by difference of phase in the respective machines, for on tracing a wave with strong harmonics, displacing it a few degrees from the original and taking the mean, the harmonics in the resultant wave are much less prominent. This small difference of phase may be the result of variable turning moment and will then give rise to synchronising currents which usually reverse in time with the engine; a change in excitation of one of the machines in order to distribute the station load as desired, will produce the same interchange of current which will now, however, not change sign.

The commencement of Part II. deals with the growth and decay of currents in large inductive circuits. I would refer Mr. Field to a paper † read before the Newcastle Section last session, in which an oscillograph was used for the same purpose, and where I gave a more complete analysis of the curves obtained.

Mr. Atchison. Mr. A. F. T. ATCHISON (*communicated*): Mr. Field's very interesting paper brings before the notice of electrical engineers the existence in practice of some phenomena which have hitherto been considered as possessing chiefly theoretical interest. The oscillograph is an instrument which opens out great possibilities for the investigation of phenomena taking place in alternating-current circuits, and it is of special value in revealing the many secondary effects which are ignored in the ordinary mathematical treatment of the subject such as is given in the greater proportion of our text-books. This treatment of alternating currents is, and will always remain, one of the most striking applications of mathematical analysis to practical work, but researches such as those of Mr. Field and others, assisted by the oscillograph, serve to show that the common methods of calculating alternating-current problems, though correct in the main, are necessarily somewhat superficial and incomplete. One of the chief omissions in the ordinary theory is the neglect

* The *Electrician*, Jan. 30, 1903, p. 609.

† *Ibid.*, April and May, 1902.

Mr. Atchison.

Mr. Mather.

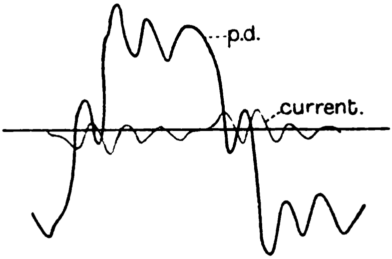
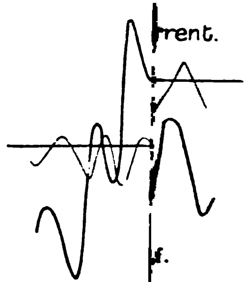


FIG. K.—Capacity 9·0 m.f.



f.

FIG. L.—

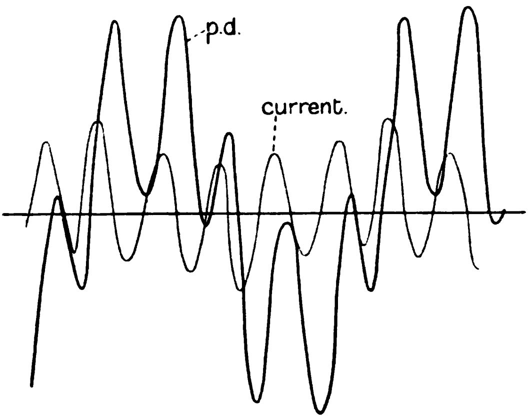
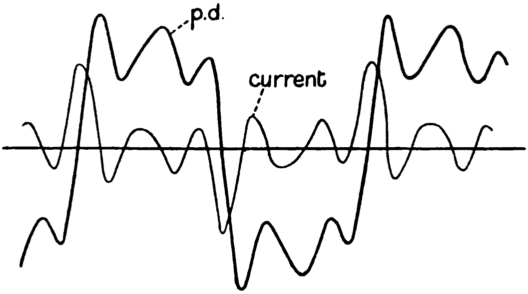
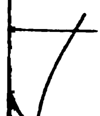


FIG. O.—27·25 m.f.
Exact Resonance with 5th Harmonic.





rcuit.

FIG. S.—36·75 m.f.

P.D. AND CURRENT OSCILLOGRAMS FROM

of the *change* in wave-form which may occur under certain conditions and which Mr. Field has brought before our notice in his admirable paper. Mr. Atchison.

The change of wave-form which may result from resonance with *high* harmonics or "ripples" of the fundamental wave through capacity of certain values existing in the circuit are very interesting, and are shown very clearly by the oscillograph. The effects however may be very much more important, when resonance occurs with *lower* harmonics.

As an example of the great extent to which these harmonics may be brought into prominence, I give a series of oscillograms taken (with a Blondel double oscillograph) from an alternator working on capacity loads of different magnitudes, bringing in marked resonance with the fifth harmonic (or overtone of quintuple frequency).

The E.M.F. wave-form of the alternator on open circuit is shown in Fig. U, containing pronounced triple and quintuple harmonics, and is found to undergo but slight alteration on a non-inductive load. A gradual increase of capacity, however, gives rise to the series of wave-forms given in Figs. K to T; very well-marked resonance with the fifth harmonic taking place with a capacity of 27·25 microfarads in circuit (Fig. O); the current during this stage being practically a simple sine wave of 5 times the fundamental frequency of the alternator, each component being naturally in quadrature with the corresponding peak and hollow in the P.D. wave. A further increase of capacity destroys the resonance, as would be expected, and the wave-forms become more normal. Even at resonance with the fifth harmonic the rise of voltage across the alternator terminals amounted to 43 per cent. (rising from 200 to 286), and had I been able to increase the capacity still further, so as to bring about resonance with the third harmonic, no doubt the effects might have been magnified to an even greater extent. The rise of voltage is of course partly due to the fact that the machine is supplying a leading current and is therefore working with a strengthened field.

It is interesting to calculate the value of the "apparent reactance" of the alternator armature, from the value of the capacity which gives rise to resonance. The frequency of the fundamental wave was 57 $\sim$ per second, and thus, taking 27·25 m.f. as the capacity corresponding to exact resonance with the fifth harmonic, we have

$$p_5 L = \frac{1}{p_5 K}$$

$$= \frac{1}{2\pi \times 5 \times 57 \times 27{\cdot}25 \times 10^6} \text{ ohms}$$

$$= 20{\cdot}5 \text{ ohms at the frequency of the 5th harmonic}$$

$$(5 \times 57 = 285 \sim \text{per sec.}).$$

i.e., a reactance of 4·1 ohms at the fundamental frequency, which is not very different from the value, 4·38 ohms, which was obtained from the "open" and "short-circuit characteristics" of the machine—the "Synchronous Reactance" of the American writers.

Mr. T. MATHER (*communicated*): The best thanks of the Institution are due to the authors for putting such valuable data before its members. Mr. Mather

Mr. Mather. The communications will, it is hoped, induce central station engineers to pay more attention to the testing department of the works under their control, with a view to locating and reducing the various losses which inevitably occur in the distribution of electric energy. We may also hope that further data as to losses in generation will be forthcoming.

The paper is specially interesting because of the large number of wave-forms met with in actual practice which it contains. These illustrate in a striking manner how the shapes depend on the load on the station and on the feeders connected with the 'bus-bars. Another valuable part of the paper is the section dealing with the measurement of dielectric losses in cables; and Table III., giving the "constants" of the wattmeters employed in the tests, is instructive in showing how much the so-called "constants" of such instruments may vary when used under different conditions.

Every one who has attempted to measure power in circuits of low power-factor with any approach to accuracy will appreciate the difficulties met with by the authors in their efforts to obtain consistent results, for the trouble rapidly increases as the power-factor decreases.

The Swinburne wattmeter behaved better than the Thomson instruments, yet, according to the value in Table III., the "constant" of the former decreased nearly 30 per cent. on changing from a leading current, power-factor 0·129, to a lagging current of power-factor 0·034. This would indicate that the pressure circuit was inductive, and I would ask whether the instrument ever gave negative readings on any of the cables tested?

The change of "constant" here observed is quite moderate in amount when compared with that shown by other instruments on the market, and which claim to be non-inductive. One I tested some two years ago gave results six or seven times as high as they should have been on a condenser circuit, and about one-third of the correct value on a choker. The true "constant," *i.e.*, the number by which the deflexions of the wattmeter have to be multiplied to get "watts," was therefore twenty times as large in the latter case as in the former. The wattmeter itself was fairly good, and the fault lay in the pressure circuit resistance coils supplied with the instrument. These coils, although wound in the way invented by Mr. Swinburne for minimising induction and capacity, are decidedly anti-inductive, *i.e.*, the current through the coils leads on the P.D. between the terminals. In fact the lead was quite measurable by the contact-maker method at a frequency of 100. On replacing the coils by another resistance of better design the readings of the wattmeter became correct within a few per cent.

As Mr. Addenbrooke has referred to the measurements of dielectric hysteresis by the aid of "air core transformers" (ironless chokers) made by Professor Ayrton and myself in 1901, I take this opportunity of answering some of his queries. In the first place I agree with Mr. Addenbrooke that the value of the power-factor for paper cables then published is somewhat higher than the average for high-tension cables of that make. I would also point out that although our measurements of power-factor gave results far less than Mr. Mordey's tests, our low values were some-

what higher than the correct ones. One reason for this is that (as was pointed out at the time, *Journ. I.E.E.*, vol. 30, p. 412) the cables tested were intended for low pressures, but were tested at 2,000 volts. The slope of potential in the dielectric was therefore greater than is usual in high-pressure cables, and this usually means greater power-factor. Another reason why the low value we gave is too high, is that the eddy current loss in the choker was neglected in these tests, and this, as I pointed out in the *Electrician* (March 8, 1901, p. 750), makes the power-factor appear higher than the true value. This effect of eddy currents loss is indicated on p. 413 of the *Journal* (vol. 30), for the tests made without the choker, Fig. D, gave the smallest power-factor, viz., 0·023, whereas those with the choker, Figs. B and C, gave 0·025. Mr. Addenbrooke's estimate of the eddy loss in our choker, 60 watts, is, however, too liberal. Possibly this is due to his taking the ampere-turns on the coil as 12,000 instead of 8,000. A third reason for our low power-factors being in excess of the correct values is found in the fact that, although the coils used in the pressure circuit were the most perfectly non-inductive resistances then made, they were slightly anti-inductive. This caused the current in the pressure circuit to lead on the P.D., and made the wattmeter read high on circuits taking leading currents. It will therefore be seen that the numbers I published in 1901 for the power-factors of paper, indiarubber, and jute cables, although only a small fraction of Mr. Mordey's value, were actually higher than the real ones. Mr. Mather.

Since 1901 I have, with the kind permission of Professor Ayrton, tested other paper cables at 2,000 volts, using in the pressure circuit of our wattmeter the improved resistances mentioned by Mr. Duddell in this discussion; the power-factors obtained varied between 0·015 and 0·019.

During his remarks Mr. Addenbrooke said one of the disadvantages of using "ironless chokers" in cable tests was the large capacity (three or four microfarads), and therefore long lengths of cable, necessary to produce resonance. In this connection I may mention a choker constructed at the Central Technical College two years ago, and referred to in the *Electrician* of March 8, 1901 (p. 750). This coil has an inductance of nearly 6 henries, and will balance about 0·4 microfarad at 100 $\sim$; it contains 1 cwt. of No. 18 wire, and absorbs only 24 watts at 2,000 volts. The question of a choker necessary to balance a small capacity is, however, merely a matter of design, and there is no difficulty whatever in making a choker suitable for testing 110 yards, or even shorter lengths, of cable.

Considerable improvement in sensitiveness and accuracy has been made in dynamometer wattmeters and shunt resistances during the past few years, and it is now possible to measure the loss in short pieces of cable. Twenty-yard lengths have been tested with comparative ease. The currents taken by such lengths of small capacity cables were very small, but were easily and accurately measured by shunting an electrostatic voltmeter with non-inductive resistances.

Tests have also been made (using improved apparatus) on condensers, with the result that the power-factor of some Swinburne

Mr. Mather condensers were found to be below 0·008, and of some condensers made by the late Mr. Cromwell Varley more than thirty years ago below 0·004. For much assistance in these tests I desire to thank Messrs. Few. Finnis, Nesfield, and Selvey, students of the Central Technical College,

It is of great interest and importance to notice that the condensers made by Mr. Swinburne some ten years ago show losses very much less than modern cables. This is highly creditable to our late President, especially as the dielectric in these condensers is very thin compared with that on high-tension cables, and the potential gradient in the dielectric correspondingly great. As condensers can thus be made with dielectric loss about half that of modern cables, it should be possible to reduce the power-factors of cables to half the values now usual. Makers of cables will doubtless give this matter their careful attention, especially where extra-high-tension cables are concerned.

In connection with Mr. Field's paper I might mention a simple way of detecting which harmonics are present in the wave-form of a machine. This is to watch the ammeter in circuit with an unloaded cable (or condenser) as the machine slows down. If any important harmonics exist the reading of the ammeter, instead of falling gradually, will remain steady, or even rise when the speed reaches a value which causes any particular harmonic to resonate. With some machines several rises may be observed before the alternator comes to rest.* The method may be made quite safe by introducing sufficient non-inductive resistance in the circuit to prevent the rises becoming excessive.

Mr. Constable. Mr. A. D. Constable, in reply, said: I have to thank you, gentlemen, on behalf of Mr. Fawssett and myself, for the considerate treatment which has been accorded to our paper, notwithstanding its shortcomings. Some of the inconclusive figures given in Table 4, with regard to cable losses, would not have been placed before the Institution had it not been for the fact that it was impossible to continue the experiments and further verify the results. The results were given as obtained, and we hoped that they would be discussed, with a view to deciding the causes of the discrepancies. I will try to treat the various points raised as far as possible in the order they occur in the paper. Mr. Minshall referred to the cost of lost units being very heavy because the greater proportion takes place at times of maximum load. It is true that about 60 per cent. of the loss occurs at times of heavy load. That means in this particular case (where the total loss is 22 per cent.) about 13 per cent. additional plant has had to be put in to supply those wasted units, beyond what is necessary for the maximum useful load. The whole annual cost of this 13 per cent. extra plant must be put down to the units wasted during the time it is running only, and although as a rule the actual running cost is rather less during heavy loads than during the day, the total cost may, therefore, be high. In certain cases also, where it is necessary to run an additional generator owing to the day-load losses, these will cost more than the average per unit generated.

* See *Electrical Review*, May 31, 1901, pp. 915–917.

Mr. Constable

A question was asked about Table 1. This Table includes the losses from the generator terminals to the feeder terminals. The percentage (0·5) is small, but it represents an expenditure of about £80 per annum, so that if £200 or £300 additional capital outlay would save, say, one-third of the loss, it would be worth while spending it.

Mr. Duddell's objections to diagrams 3 and 4 are unfounded, as he hopes. We had a large non-inductive resistance in series with the pressure coil of the wattmeter in all cases, and also in series with the volt coil with the oscillograph, but it is omitted in the diagrams. The total resistance of the wattmeter shunt circuit was about 7,000 ohms, so that the pressure coil is taking rather less than 1 per cent. of the total current in the resistance R_2, Diagram 3. In connection with Diagram 3, Mr. Duddell asked how we obtained the power-factor with a leading current. I will try to explain this by means of a diagram.

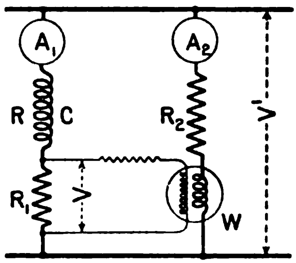


FIG. V.

R_2 is a non-inductive resistance in series with the wattmeter current coil, and the current in it, A_2, is in phase with the applied volts, V'. C is the ironless choker with resistance, R, and in series with it is the non-inductive resistance, R_1.

The wattmeter pressure coil is connected to the terminals of R_1, the voltage across which is V. A_1 is the current in C and R_1.

V is in phase with A_1, and since A_1 lags behind V', the current A_2 is leading with regard to V.

The watts absorbed by the choker $= A_1^2 R$,

" " " " $R_1 \quad = A_1 V$;

the total watts in the choker circuit therefore equal $A_1 (A_1 R + V)$, the corresponding volt-amperes $= A_1 V'$; therefore the power factor of the choker circuit is equal to $\frac{A_1 (A_1 R + V)}{A_1 V'} = \cos\theta$, where θ is, by the usual definition, the equivalent angle of lag of A_1 behind V'.

The watts indicated by the wattmeter will be $A_2 V K \cos\theta$, where $K =$ constant of instrument, so that—

$$K = \frac{\text{Reading}}{A_2 V \cos\theta} = \frac{\text{Reading} \times V'}{A_2 (A_1 R + V) V} \left(\begin{array}{c}\text{R.M.S.}\\ \text{values}\end{array}\right).$$

If now we are not dealing with sine waves, the voltages across C and R_1 respectively may be different functions of the time, so that $A_1 R$ and V cannot strictly be added, but with the wave forms used in the calibration, the error thus introduced will be very small.

[*Note added later.*—I am now obliged to admit, on further consideration, that the possibility of errors being introduced by accepting this calibration may be greater than was at first supposed. In reply to Mr. Mather's query, I may say that the wattmeters used in our experiments did not at any time give a negative reading on the cables tested.]

Mr. Constable.

It is true that the calibration is only quite correct for the particular wave forms used, and in the cable experiments the wave forms were sometimes very different. We do not profess that all the figures in Table 4 are absolutely accurate, but what we attempted to show and tabulate in Table 3 was that the wattmeters gave an approximately correct reading for both lagging and leading currents and for considerably different wave forms. We agree with Mr. Duddell that the wattmeter method is by far the best to obtain the power factor in a cable if a wattmeter can be obtained which will indicate watts only and not concern itself with several other things as well. I am glad to hear that such an instrument has been devised by Mr. Duddell. The motor alternator method might be of use, but it is rather complicated and requires a number of simultaneous readings and adjustments to make it practicable. Mr. Mordey rather advocated the calorimetric method, which certainly cannot be used after the cable is laid, and if the cable is coiled in a tank inaccuracies are introduced, as Mr. Minshall has found. The method might be used if a specially lagged trough were made, of considerable length, as suggested by Mr. Mordey and Mr. Minshall, and the temperature rise in a given time measured; but even in the worst cable, No. 7, the watts lost per yard are only about 0·6, so that there would be some difficulty in measuring the temperature rise accurately in an iron trough, such as should be used.

Mr. Duddell's vigorous criticism of Table 4 was perhaps justified by the appearance of some of the figures. We do not profess that these figures are all even approximately accurate. Where great discrepancies appear, the figures are inserted to show what divergence may occur even in experiments made with care. Cable No. 7 is without doubt abnormal, while the variations in Nos. 4, 7, and 9 are hardly larger than would be expected from the conditions. Cable No. 10 is an exception. Of the two very different values obtained for that cable, the second, namely, 0·024, was obtained with the choker in parallel with the cable, and is therefore probably the more accurate. The low insulation, 2 Ω, is due to switch base leakage, and not to the cable. In the case of experiments 1 to 13 the figures are the means of several sets of readings. The frequency in all cases was 60 $\sim$, within 1 per cent. With regard to cable 11, Mr. Duddell accused us of arbitrarily selecting results and of failing to draw the proper inferences from the experiments. The reason for selecting experiments 18 to 20 in preference to 15 to 17 are given in the paper on p. 716. These experiments were made with different machines. Nos. 18 to 20 were taken with a 120-kw. machine, whilst Nos. 15–17 were taken with a 30-kw. machine of the same type, and there was no other difference to account for the former being the much smoother waves. It is practically impossible to work out oscillograph curves when the waves are very peaked, but the results of the smoother waves should be fairly accurate, though we do not suppose that either result is quite correct. Unfortunately we had no suitable wattmeter available at the time, and there has been no opportunity of checking the results since. As to the effect of the wave-form on hysteresis loss, we prefer to judge by the majority of the experiments, which show there is not such a great

Mr. Constable.

difference as experiments 15 to 20 indicate, although there is some variation. Mr. Duddell also remarked on the low result obtained for the watts absorbed by cable 12. We only obtained 900 watts, whereas the figure should have been about 1,100, summing up the watts absorbed in the various component parts, after correcting for voltage. But again this experiment was made without a wattmeter, and so there is a good deal of possibility of error in working out the results.

Mr. Field questioned Table 5. In that table the figures in the last column were calculated from data obtained by experiment. We took the readings on cable No. 7 and observed the watts absorbed, but as this was an abnormal case, we wished to correct them for a hypothetical paper cable. The results are therefore only approximate, as stated. Our experience goes to confirm Mr. Field's remarks to the effect that a dielectric with a high hysteresis loss has a low disruptive strength. With regard to the magnetic field stated to exist round a cable, since writing the paper we have made some further experiments. A large alternating current, 250 amperes at 60 ∿, was passed through the inner and back by the outer of 50 ft. of cable of the type of No. 11, Table 4, in a straight length. At the centre a piece of cast-iron trough 6 ft. long was placed. Three feet of the trough had the cover removed from it. A search coil 18 in. by 5 in., consisting of 200 turns of fine wire connected to a telephone, was fixed (at the same distance from the centre of cable) (A) over the uncovered portion of cable, (B) over the uncovered portion of trough, (C) over the covered portion of trough. In position (A) the noise was very loud, at (B) it was much less, and at (C) there was practically silence. The noise in position (A) was roughly the same as that produced by a current of 2 amperes in a long straight wire at the same distance from the coil (about 2½ in.). That seems to show that there is an external magnetic field which is practically all shielded by the iron trough. A piece of concentric armoured cable behaved in the same way, but the shielding effect of the thin armour was slight. Cable 7 has the outer conductor of a rather open strand, so that the external field may be greater than in the case of No. 11, which has a closely laid outer. (It is difficult to see how this field can exist, however.) It will be of interest to pursue these experiments and investigate the strength of field in the iron trough at ordinary loads. It still appears possible that some of the apparent dielectric hysteresis loss is really iron loss in the case of No. 7 cable.

Mr. Mordey stated he thought it was more economical to allow several transformers to share the load than to keep one or two fully loaded. We admit that. Our point, however, was that it was very wasteful to keep many transformers on at times of no load, and these times make up the greater part of the 24 hours.

Mr. Andrews referred to the danger of switching off transformers. I may say that during six years not one of the fifty odd transformers in Croydon has broken down due to repeated switching off and on. That they are all of the oil-cooled type may be partly responsible for this. Small punctures in the insulation, if they exist, may be filled up with oil before the transformers are again used. The oil, too, will act as a

Mr. Constable.

lubricant and prevent abrasion of the insulation due to vibration and alternate expansion and contraction. The mean temperature of the transformers is kept down by the practice of switching off transformers not required. With reference to the remarks on meters; in direct-current systems, ampere-hour meters of considerable capacity are obtainable which will record accurately on a 200-volt 5-c.p. lamp. If there are no very satisfactory alternating-current ampere-hour meters, it is possible to obtain accurate energy meters which require an exceedingly small shunt current and which have no moving contacts. Meters which require frequent inspection, cleaning, and adjusting cause more than half the trouble between the supply authorities and the consumers.

Mr. Addenbrooke has mentioned that the loss in a cable increases more than proportionately to the rise in voltage. We have found that to be the case; in fact, in some experiments we made, the increase has been more than proportionate to the square of the voltage. I am glad to hear that Mr. Addenbrooke also finds a considerable increase in the loss when the cable is surrounded by iron. Mr. Sparks mentioned the dangers of running up an alternator on a cable slowly. That is illustrated by curve 13, sheet C, in the paper. There we had an alternator running at about half speed under otherwise ordinary conditions on a cable, and the voltage rose to about 6,000 maximum on a 2,000-volt system.

I do not think any other points raised remain to be dealt with, and will therefore conclude my remarks by again thanking you for your kind reception of this paper.

[*Note added later.*—In all cases the C^2R loss due to the capacity current is included in the dielectric hysteresis loss, its value being only a small percentage of the total.]

Mr. Field.

Mr. M. B. FIELD (*in reply*):* I think the best way to answer the many remarks that have been made upon my paper will be to deal first with the more direct criticisms, and after that to cover with a few general remarks the further comments of other speakers. Referring first to Professor Hay, I certainly grant that to be lax with one's terminology is a most serious error for any one to fall into, and perhaps I am to a certain extent guilty in this respect, but I think that Professor Hay has rather exaggerated my delinquencies. First, with regard to the *secohm*. I suppose I should not defend the term, as it has now, by universal consent, been discarded, but it seems to me such a rational term, and "henry" seems anything but that. "Secohm" gives one at once an idea of what it is. Coefficient of self-induction may be said to be defined by the usual equation—

$$V = RC + L\frac{dC}{dt}$$

and is really the back E.M.F. in volts in a circuit when the current is altering at the rate of 1 amp. per sec. As regards its dimensions L is

* Mr. Field's reply to the discussion on his paper at Glasgow (see p. 694) is included here.

$V\left(\frac{d}{d}\right)\frac{t}{C}$ and therefore of the nature of a time multiplied by a voltage Mr. Field. and divided by a current, hence the term sec-ohm.

Ohmic Resistance: The adjective "ohmic" may be superfluous, but no one can call it misleading. I use it to distinguish resistance-proper from "apparent" resistance, with which the paper deals considerably. I have referred to certain combinations of self-induction and capacity as behaving, as far as the external circuit is concerned, as a resistance of so many ohms. This is, of course, only an apparent resistance, as in most cases it is only true at one particular frequency that the combination could be exactly replaced by a resistance. In dealing with such combinations I maintain that it is not at all out of place to draw the distinction between resistance-proper and apparent resistance by applying the epithet "ohmic" to the former.

Self-induction of an Alternator: Professor Hay states I have used this term in more than one sense. I consider I have been most careful to explain the exact sense in which I have used it. I have pointed out what I consider the distinction between self-induction and armature reaction is. I have pointed out that an alternator cannot strictly be said to have any true coefficient of self-induction, as this depends on, and varies with, the saturation of the field-magnet system, the position of same relative to the armature coils, and the strength of the armature currents. I have pointed out the variable nature of this coefficient; I have then *for shortness* included in the term "self-induction" the effect of armature reaction, saying, "In talking of the self-induction of an alternator I shall, for the purpose of this paper, include in the term, armature reaction, *i.e.*, I shall refer to that self-induction (whether with constant or variable coefficient) which, inserted in series with a reactionless and self-inductionless machine, would give the same characteristics." Surely I cannot be blamed for indefiniteness here.

Synchronous Impedance: This is an American term. I think it implies what it is, viz., the impedance at synchronous speed. It includes self-induction and armature reaction, being determined by the comparison of the short-circuit armature current at synchronous speed at a given excitation, with the no load E.M.F. at same speed and excitation. The term is quite a well-known one.

I was somewhat surprised at the rather dogmatic way Professor Hay denied the correctness of the statement on page 662 that the combination (Fig. W.) behaves under *all* conditions, as far as the external circuit is concerned, as a resistance of r ohms provided $K = \frac{L}{r^2}$ The text may be a little badly worded here, but when I say that this is true for all frequencies and for periodic and unperiodic functions, it is perfectly evident that the condition represented by (9) which refers to one particular frequency, has nothing to do with the matter. I did not attempt to prove my statement because the proof is to be found elsewhere. I thought it was a matter of common knowledge, for certainly Professor

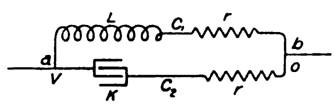


FIG. W.

Mr. Field. Perry has been in the habit of giving this case as an example to his students for fourteen or fifteen years. The proof is to be found on page 247 of Perry's "Calculus." This combination is, however, interesting from many points of view, and is worth study.

In the first place we see that if energy be stored either in the self-induction or the capacity, and this be allowed to discharge in the closed circuit, the combination is the critical one at which the discharge just ceases to be oscillatory.

Secondly, however V may vary, the total energy stored in the self-induction at every instant is equal to that stored in the capacity, for remembering $L = K r^2$ we may write, using Professor Perry's symbol θ—

$$V = r(1 + K r \theta) C_1$$
$$= \left(r + \frac{1}{K\theta}\right) C_2$$

The energy stored in the self-induction at any instant is $\frac{1}{2} L C_1^2$; and in the capacity $\frac{1}{2} K (V - r C_2)^2$. But it is clear that both these expressions may be written in the form $\frac{K}{2(1 + r K \theta)^2} . V^2$; hence, however V may have varied, the total energy stored at any instant as expressed by this formula is the same both for self-induction and capacity.

It is further interesting to note that if current be flowing through the combination from the external circuit so that a certain amount of energy is stored both in the self-induction and the capacity, on suddenly interrupting the external circuit, although the stored-up energy will discharge itself in the closed loop, there will be no difference of potential between the points *a* and *b*. Professor Gray has pointed out an error I have fallen into where, on page 668, I determine the coefficient of self-induction of an alternator (working under certain conditions) by taking the slope of the synchronous impedance curve.

I have really assumed that the equation $V = R C + L \frac{dC}{dt}$ still holds for a circuit containing iron (and therefore with a variable coefficient of self-induction) provided we express L in the above equation as a function of C. Professor Gray's criticism is quite justified. The true equation should be—

$$V = R C + \frac{d (L C)}{d t}$$
$$\text{or} \quad V = R C + L \frac{dC}{dt} + C \frac{dL}{dt}$$

that is to say, I have left out of account this last term. As, however, I have based no calculations on this, the drift of my argument is not affected.

Professor Carus-Wilson has found fault with some of my mathematics, asking whether the minus signs on page 691 in the expressions for V_0 should not be positive signs. Several of the professors have pointed out that the mathematics of the subjects treated in my paper have been worked out before. It is hardly necessary for me to say that I am perfectly aware of this, and have stated so myself in the

paper, and for this reason I have avoided mathematical treatment as far as possible. The theory of electric oscillations in capacity self-induction circuits was first worked out by Lord Kelvin between fifty and sixty years ago. In Part II. I have therefore merely stated the general differential equation which holds for such a circuit, and then given the particular solutions applicable to the cases experimentally investigated. (I have, it is true, as a slight digression, discussed briefly the characteristics of the damped oscillations, to remind those readers unfamiliar with the subject.) Professor Carus-Wilson has referred to Mr. C. P. Steinmetz's paper on this subject. My attention was called to this after my own was mostly written. Mr. Steinmetz in his admirable work treats the whole subject more as a mathematical problem. I must say I found the paper rather long and difficult, and the more important conclusions arrived at by making certain simplifications at the end of the work, I have tried to compass without the mathematics. With regard to Part III., Professor Carus-Wilson has referred to the work of Houston and Kennelly. These, of course, are not the only writers on this subject, *e.g.*, C. P. Steinmetz, Bedell, and Crehore, etc., and I think that the work of even these writers is to a certain extent an adaptation of Fourier to electrical problems similar to the heat problems treated mathematically by that physicist. Being again fully aware of this, I have satisfied myself with stating merely the general differential equations, and the particular solutions applicable to the case I am considering, viz., resonance at the end of a long unloaded three-phase cable, due to a high order of harmonic, which I have shown may exist in a practicable alternator, and my intention has been to arrive at the conclusion, by means of a numerical result, as to whether such resonance is likely to prove dangerous or not. Mr. Field.

Coming now to Professor Carus-Wilson's query *re* positive and negative signs, perhaps the best way will be for me to show here how the expressions in question are arrived at:—

The solutions given in the paper for v and c are (see page 689)—

$$v = V_1 [\epsilon^{-ax} \sin(2\pi n t - a x + \phi) + \epsilon^{-a(2l-x)} \sin(2\pi n t - a(2l - x) + \phi)]$$
$c =$ etc.
$a =$ etc. . . . . (1)

These equations can of course easily be verified by differentiation.

We see that when $x = l$, $c = o$, which is the condition of an unloaded cable; V_1 and ϕ are arbitrary constants, but if we say that at the beginning of the cable we will define the voltage as $V_0 \sin 2\pi n t$, we can find V_1 and ϕ as follows:—

Inserting in (1) $x = o$

$$V_0 \sin 2\pi n t = V_1 [\sin(2\pi n t + \phi) + \epsilon^{-2al} \sin(2\pi n t - 2al + \phi)]$$

Let $2\pi n t + \phi = o$, then

$$V_0 \sin\phi = V_1 \epsilon^{-2al} \sin 2al \quad \ldots\ldots\ldots \quad (2)$$

Let $2\pi n t + \phi = \frac{\pi}{2}$, then

$$V_0 \cos\phi = V_1 (1 + \epsilon^{-2al} \cos 2al) \quad \ldots\ldots \quad (3)$$

Mr. Field. Dividing (2) by (3) we have

$$\tan\phi = \frac{\epsilon^{-2al}\sin 2al}{1+\epsilon^{-2al}\cos 2al}$$

Squaring (2) and (3), adding and taking the square root, we have

$$V_0 = V_1\sqrt{1+\epsilon^{-4al}+2\epsilon^{-2al}\cos 2al} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

I then state that maximum resonance will occur when $al = \frac{\pi}{2}$, the rise of voltage occurring at the free end of the cable. Inserting in (1) $x = l$, $l = \frac{\pi}{2a}$, we have as the voltage at the far end

$$2V_1\left[\epsilon^{-\frac{\pi}{2}\frac{a}{\alpha}}\sin\left(2\pi nt+\phi-\frac{\pi}{2}\right)\right]$$

the maximum value of which is

$$2V_1\epsilon^{-\frac{\pi}{2}\frac{a}{\alpha}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

combining (4) and (5), and remembering that $\frac{a}{\alpha} = \tan\theta$, we have the expression

$$\frac{2\epsilon^{-\frac{\pi}{2}\tan\theta}}{\sqrt{1+\epsilon^{-2\pi\tan\theta}\mathbf{-}2\epsilon^{-\pi\tan\theta}}}V_0 \quad \text{or} \quad \frac{2\epsilon^{-\frac{\pi}{2}\tan\theta}}{1\mathbf{-}\epsilon^{-\pi\tan\theta}}V_0 \quad . \quad . \quad (6)$$

These are the expressions to which Professor Carus-Wilson objected, asking whether the minus sign which I have shown in thick type should not be positive. I would point out that whether this sign is positive or negative entirely depends on the term $\cos 2al$ in (4), and hence on the length of the cable under consideration. Where $l = \frac{\pi}{2a}$ the case here considered $\cos 2al = -1$, where $l = \frac{\pi}{a}$, $\cos 2al = +1$. This latter case, however, viz., where the length of the unloaded cable equals one half of the wave length is not a condition of resonance. With the correct length to give rise to resonance, the E.M.F. at the free end will be greatest when the copper resistance is smallest. If we assume this becomes vanishingly small, $\tan\theta = o$, and the voltage at the free end of the cable is for $l = \frac{\pi}{2a}$, infinity; and for $l = \frac{\pi}{a}$, V_0; that is, in this case, the voltage at both ends of the cable is the same.

This hypothetical case of a length of cable equal to one quarter wave length where the copper resistance is negligible is of great interest. Mr. Steinmetz has pointed out that at the one particular frequency it behaves as a constant potential to constant-current transformer, *i.e.*, if constant potential be maintained at one end, constant current will be given out at the other irrespective of the nature of the load (except, of course, in the case where the cable is an open circuit, when the potential rises to infinity, as above.) That this must be so is evident from the equations for v and c; for however the cable is loaded

the same form of expression holds for the current at one end of the cable as for the voltage at the other, and *vice versâ*, the coefficients only differing; hence if at one end the voltage be maintained constant, at the other end the current will remain so, and *vice versâ*.* Mr. Field

I do not altogether agree with Professor Carus-Wilson in supposing that this class of resonance will never be dangerous. Suppose an E.M.F. represented by the wave Curve XV. were applied to such a cable as I have assumed in my calculation, and the 13th harmonic were transformed up twelve times. At the far end of the cable the harmonic might quite easily be twice as important as the fundamental, in which case the maximum voltage would be nearly three times that of the fundamental.

Messrs. Constable and Fawssett in their excellent paper indicate that they expected to find a change of wave shape at different points along a fairly long cable, unloaded, upon which they experimented, and expressed surprise in failing to do so. I think myself that the length of cable necessary before any appreciable change would be observed is far beyond anything they have at Croydon. I do not think either that a change of frequency (within reason) would have created the expected variation as supposed.

In this connection I think it will not be altogether out of place here to give a comparatively simple graphical method for determining the current and voltage at any point of a long cable loaded on a more or less inductive circuit. Clearly we need only consider one harmonic or a sine function of E.M.F., for however complicated the applied E.M.F. may be, each term of the Fourier's series into which it can be expanded may be treated in like manner.

In the first place it is clear that the solution given on page 689 becomes for a loaded cable

$$v = V'\epsilon^{-ax}\sin(2\pi n t - ax + \phi') + V''\epsilon^{-a(2l-x)}\sin(2\pi n t - a(2l - x) + \phi'')$$

$$c = \frac{V'}{\gamma}\epsilon^{-ax}\sin(2\pi n t - ax + \phi' + \theta) - \frac{V''}{\gamma}\epsilon^{-a(2l-x)}\sin(2\pi n t - a(2l - x) + \phi'' + \theta)$$

where

$$\frac{1}{\gamma} = \frac{2\pi n \kappa}{\sqrt{a^2 + a^2}} \quad \text{or} \quad \sqrt{2\pi n \frac{\kappa}{1}}$$

* In this connection my brother, A. B. Field, has pointed out that the following combination of self-inductions and capacity acts as a constant potential to current transformer, provided it is loaded on a non-inductive load, and n is such that $2\pi n = \sqrt{\frac{1}{LK}}$; the proof is simple; the combination is very interesting. I understand that Mr. Steinmetz first called attention to this combination.

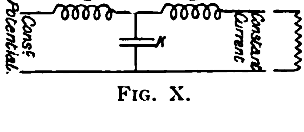


FIG. X.

Mr. Field. and where V', V'', ψ', ψ'' are determined by the terminal conditions—

$$x = o,\ v = V_o \sin 2\pi n t\ ;\ x = l,\ c = \frac{v_l}{\left(r + l\frac{d}{dt}\right)}$$

v_l being the value of v, obtained by putting in the value $x = l$, and r and l are the resistance and coefficient of self-induction of the circuit external to the cable, hereafter termed "the external circuit." Let the impedance of this circuit or $\sqrt{r^2 + 4\pi^2 n^2 l^2}$ be denoted by I'. We see that v and c consist each of an original and a reflected wave, and that the phase of each wave at any particular instant changes uniformly as we go along the cable. The difference of phase at two points separated by the distance x is ω where $\omega = a x$, whereas the ratio of the amplitudes at these points is $\epsilon^{\omega \tan \theta}$. If, now, we draw a logarithmic spiral, $r = \epsilon^{\omega \tan \theta}$ (see Fig. Y), of which the co-ordinates are r and ω, and say that the radius O a represents in magnitude and phase the original wave at the far end of the cable, then O b will represent the magnitude and phase at a distance x_1 from the end, where $\omega_1 = a x_1$. Similarly if O a' represent the reflected wave at the end of the cable, O b' will again be the phase and magnitude of the same at distance x_1 from end. The conditions which obtain at the end of the cable are these : Let O V, Fig. Z, be the voltage, and O c the current. I have shown these in two distinct diagrams for the sake of clearness, preferably they should be combined in one. O c = O V/I' and cos χ is the power factor of the circuit supplied by the cable. Now O V is the resultant of two waves, say O d and O e ; corresponding to each of these is a current wave, of which the amplitudes are O d/γ, O e/γ, and each is in advance of the corresponding potential wave by the angle θ. The resultant of O d and O e is O V, while the difference of the two corresponding current waves is O C. This is evident from the form of the equations v and c.

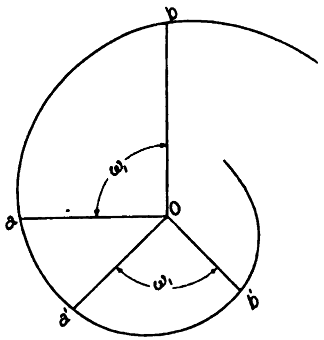


FIG. Y.

Draw a line O P, set back from O c by the angle θ. Bisect O V and draw through the centre a line parallel to O P of length O V . $\frac{\gamma}{I'}$, so that this vector is in its turn bisected by O V. Complete the parallelogram, of which these vectors are the diagonals, then O d, O e, represent the two voltage waves, because they give a resultant O V, and when we draw in the corresponding current waves in the current diagram, or O d', O e', these are such that (by construction) O d' — O e' = O c.

We have now only to superimpose the logarithmic spiral on the top of each diagram, rotate O d, O d' forwards through the angle ω' ($= a\,l$) and O e, O e' backwards through the same angle, increasing or decreasing the magnitudes of these vectors in proportion to the value of the polar

co-ordinate of the spiral, to find the values of the original and reflected voltage and current waves at the beginning of the cable. Taking the resultant of the two voltage vectors and equating this to $V_0 \sin 2\pi n t$ we fix the scale of the diagram, and the datum from which time is measured. For example, suppose $a l = \frac{\pi}{2}$ we rotate O d forward through a right angle and increase it in the proportion O s' : O s, we rotate O e backwards through a right angle and decrease it in the proportion O t' : O t. These two vectors represent the magnitude and phase of the original and reflected waves at the beginning of the cable. Their resultant is O V_0. Since the applied E.M.F. is $V_0 \sin 2\pi n t$ the length O V_0 represents the voltage V_0 which fixes the scale of the diagram, while all phase relations of currents, voltages, etc., are referable to O V_0. It is thus clear that by determining the values of the original and reflected waves and taking the sum or difference as the case may be, the true value of voltage and current at any point of the cable may be determined. Mr. Field

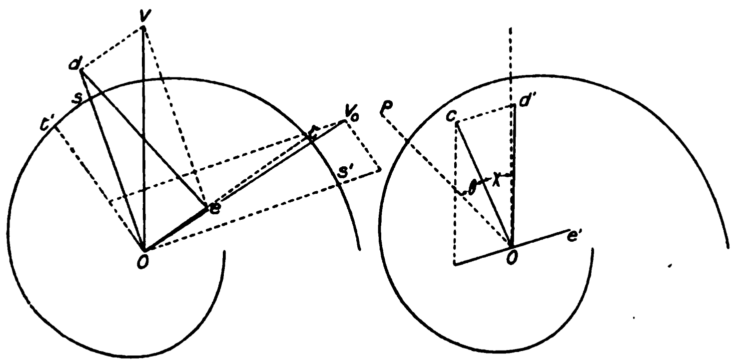


FIG. Z.

Professor Carus-Wilson asked for a further explanation of the footnote on page 688. I thought this was sufficiently clear. $\rho \lambda \kappa$ of Part III. have entirely different dimensions from R L K in II. The latter are resistance, self-induction, and capacity respectively, the former are the same physical quantities divided by a length, or resistance, self-induction, etc., *per unit length*. In Part II. $\sqrt{\frac{1}{LK}}$ is a frequency, or of the dimensions of T^{-1}; in Part III. $\sqrt{\frac{1}{\lambda K}}$ is a velocity or $\frac{\text{length}}{\text{time}}$; it was to keep this distinction clearly before us that I resorted to the Greek letters in Part III.

I do not agree with Professor Carus-Wilson in his remarks *re* the misapplication of the term resonance, nor do I think that Houston and Kennelly were the originators of the term. Resonance was known and understood in other branches of physics, vide Helmholtz's Resonators (accoustic), long before Houston and Kennelly's paper. One may say

Mr. Field. that the best definition of resonance is "Synchronism between the natural and forced vibrations of a system." With this definition the phenomena investigated in Part I. are true resonance effects. We are dealing with combinations of capacity and self-induction which have a definite periodic time of their own (natural vibrations), if now the frequency of the supply (or forced vibrations) correspond with the natural, we get serious magnification of the amplitude of the vibration or *resonance*. As another example, the periodic time of the vibrating portion of the oscillograph is say, $\frac{1}{10000}$th of a second, suppose we passed an oscillatory current of the same frequency through the strips we should have a case of mechanical resonance, the amplitude of vibration being largely in excess of that which would normally correspond to the current flowing. This is *resonance* in the strictest sense, and Professor Carus-Wilson is unduly limiting the use of the expression in restricting it only to such phenomena as are dealt with in Part III. In Part II. I grant it is hardly in order to apply the term "resonance" to the phenomena discussed, as there we are only dealing with the natural vibrations, but I have pointed out on page 682 that while in Part I. we have been dealing with cases wherein the frequency of the supply synchronised with the natural oscillations (or frequency of supply $= \frac{1}{2\pi}\sqrt{\frac{1}{LK}}$), in Part II. we are dealing *only* with the natural oscillation, the frequency of which is the same as the above, viz., $\frac{1}{2\pi}\sqrt{\frac{1}{LK}}$. We may almost consider the latter case as a particular instance of the former, where the amplitude of forced oscillation is zero. At any rate, the laws governing the two cases are so similar that I have classed the latter, though possibly incorrectly, as a resonance effect.

Professor Maclean (Glasgow) has contributed some very interesting remarks *re* harmonics present in some of the wave forms I have reproduced. It is quite evident that in a three-phase Y connected generator the 3rd, 6th, 9th, etc., harmonics can have no existence.* If, however, the voltage wave between one terminal and the neutral point had been reproduced (*i.e.*, of one leg of the winding only) I fully believe that traces of the 3rd, 9th, 15th, etc., would have been found.

I have pointed out that in such a generator the only harmonics which can exist (voltage being taken between two line wires) are given by the expression $6n \pm 1$, where n is any whole number. If we give n a value equal to the number of slots per pole per phase we get the two harmonics, which will in all probability be the most predominant. In the curves under examination we should expect to find only the 5th, 7th, 11th, 13th, 17th, 19th, etc. Similarly with regard to the ripple in the rotary D.C. E.M.F., as Mr. Hird has pointed out, the 5th and 7th will produce a ripple of six times the normal frequency, the 11th and 13th of twelve times, and so on; hence the order of ripples will always be a multiple of six.

* I have to thank Dr. J. B. Henderson of Glasgow University for first calling my attention to the fact that on theoretical grounds these harmonics must be non-existent in the alternators under discussion.

It is to be observed that since the 11th and 13th harmonics will both produce a ripple in the D.C. E.M.F. of the rotary of twelve times the normal frequency, these may either neutralise or augment each other. The cases are therefore possible that a large ripple may appear in the D.C. E.M.F. due to relatively small harmonics in the A.C. wave, or again, a perfectly straight D.C. E.M.F. line may result from an A.C. E.M.F. wave having considerable harmonics. The same thing of course applies to the other pairs of harmonics. Professor Maclean has drawn attention to the existence of a considerable 5th harmonic in certain wave forms. The somewhat rough and ready explanation I have given on page 657 of the cause of the existence of the 11th and 13th harmonics is based entirely on the number of teeth in the armature. I point out that there are twelve teeth per period, therefore we might expect twelve irregularities in the magnetic curve, hence the reason for considering the magnetic curve represented by $F N \sin k t + a (1 - \cos 12 k t)$, etc.; following out the argument of the paper it would of course have been incorrect to assume an expression such as $a (1 - \cos 6 k t)$ as Professor Maclean indicates. On the other hand, the existence of a pronounced 5th harmonic may very readily be imagined as due to the crowding together of the copper in the armature. It is quite conceivable that if the machine were a smooth-core alternator, but with the copper crowded together in the same way as in the actual case, a 5th harmonic might be the result. It is to be regretted that Professor Maclean had not time to continue his analysis of the curves published and determine in what proportion the 13th was present. Mr. Field.

Coming now to Mr. Duddell's remarks, I would say in the first place that I am quite aware of his beautiful photographic contrivance for obtaining a continuous record from the oscillograph, but I could not use it on the score of expense. The makers quoted me something like £50 for the apparatus, and I understand that it is a comparatively easy matter to reel off £10 or £12 worth of films in a few minutes.

I therefore resorted to the dark slide shown in the paper; these cost me about 30s. a piece and ½d. per exposure. Of course, I was dealing with periodic effects, and those effects which were not really periodic I made periodic by employing the contact maker already described. I consider I obtained excellent results with my dark slides, and I can strongly recommend the use of the same for similar work. Where, however, it is desired to study such effects as those when arcs break out, etc., I admit there is no way of doing it satisfactorily except by the very expensive continuous film device.

Mr. Duddell referred to the effect on the A.C. voltage of a rotary, of sparking at the commutator, and stated that he would not like to say what might happen on account of resonance on the A.C. side should this sparking become bad. I have myself observed similar effects produced by sparking, not on a rotary, but at the contact breaker already referred to. I do not think, however, that this is likely to give rise to dangerous oscillations in the cable system. It appears to me that there is just as much likelihood of such effects occurring on the D.C. side as the A.C., and if they are serious, some such effect would have been

Mr. Field. noticed and recorded before this in connection with sparky D.C. generators which supply considerable cable networks. In the paper, however, I have called attention to the possibility of resonance with D.C. machines due to slight periodic voltage fluctuations corresponding to the number of armature slots or commutator segments, *e.g.*, compare ripples on Curve IV.; and although resonance under these circumstances would not probably assume any very great dimensions I think that in the case of rotary converters the effect due to the accentuated ripples in the D.C. voltage illustrated in the paper might become very serious.

Attention has been drawn by several speakers to the danger in running up a generator to full speed, when already excited and connected to a cable system. This is a point I attach considerable importance to and have dealt with myself in the paper. We did not appreciate the fact at first at all at Glasgow, but nevertheless noticed a curious effect during the process of starting up and shutting down. At a certain speed or speeds, as mentioned by my former assistant, Mr. S. Blackley, a kind of static sparking was observable between the live metal portions of the Westinghouse high-tension breakers into the wooden arms on which they were carried. It was afterwards found that these effects corresponded with the critical speeds at which partial resonance occurred.

Mr. Duddell referred at some length to the form factor; he attaches very great importance to the strain put upon the system due to a high form factor. In my paper I have said it is a mistake to attach too much importance to these effects, and to get frightened at them, though I most strongly urge the advisability of every engineer investigating fully what is going on inside his system so that he is in a position to appreciate and overcome any difficulties which may be introduced thereby. I may say, however, that at Glasgow, with the exception of the one isolated case above mentioned, there was nothing to indicate that anything abnormal was occurring at all. It was only because I expected to find deformations of wave shape from theoretical considerations that I was led to search for the results here published, and I may say that in some instances a very considerable amount of experimenting was necessary before I found the critical conditions.

When I was recently in the States I made a special point of asking central station engineers whether they experienced difficulties in working from these causes, and the almost invariable answer I received was that but for the theoretical writings of certain authors they would not know that such phenomena as resonance existed at all. Of course I know that certain stations over here have had considerable trouble with cables and apparatus, but nevertheless I am inclined to think that with modern up-to-date systems of cables and apparatus there is not much to fear. As regards form factor, even with a very distorted wave such as Curve XV., it does not exceed 2 or 2·2, whereas the form factor of a sine-wave is 1·4, *i.e.*, the maximum E.M.F. in the former case is only about 50 per cent. greater than in the latter, and if the insulation of the system won't stand this the sooner it breaks down and is taken out the better.

Another reason why I urge that too much importance should not be attached to the form factor is this: At the last meeting I indicated that unless very excessive voltages be applied there is strong probability that the determining factor as to whether an insulating material will break down or not is the heat developed per unit volume and the actual deterioration of the material thereby caused. If this be so, it is the R.M.S. of the voltage wave we have to consider and not the form factor. I do not wish to be misunderstood here; if it is a question of the insulation breaking down due to sparking across some air-gap or the like, I do not dispute that it is the form factor we have to look to, but what I mean is, if we consider a moderate excess of voltage which will not instantly break down the insulation, but after, say, 5 or 10 minutes, or even half an hour, then the primary cause of breakdown will probably be due to excessive local heating at the weakest spot, and in such a case a partial resonance producing a greater form factor is not serious provided it does not increase the R.M.S. value. I say this with considerable diffidence, and I'm afraid Mr. Duddell will not agree with me. I only wish that Mr. Duddell had written a paper on this subject instead of myself; he has made a large number of experiments and has a fund of information which *ought to be published* for the benefit of the electrical industry; I hope he will, in communicating his remarks to the Journal, expand them considerably and give us further details of his careful study of this most important subject. Mr. Field.

Major Cardew suggested that the assumptions made in the paper as to the suddenness with which a circuit is made or broken are untenable. He suggested that the switch itself had a certain variable amount of capacity which was really in series with the capacity of the cable, and on closing the switch this capacity was gradually reduced, thus gradually raising the potential of the cable before the circuit is actually closed. Now if we take the capacity of a ·2□″ cable, we find that it is about equivalent to that of two plates 750 sq. ft. area, or 28 feet square, separated by, say, $\frac{1}{8}''$. What can the capacity of the metal parts of the switch be in comparison with this? Probably not more than $\frac{1}{10000}$th part until the contacts came within striking distance, then a spark passes and the insulation of the air-gap being totally broken down, the circuit may be said to be closed instantly. Again, on opening a circuit Major Cardew suggested that the air arc which is formed and gradually lengthened causes the current to gradually die down. Now experiments show that this is very far from being the case. A high-tension air arc seems to finally extinguish itself with what might almost be termed explosive suddenness, even though it may have lasted several seconds previously. Whatever be the reason it has now been established beyond the region of doubt that the high-tension air arc is about the most vicious phenomenon possible in setting up high potential oscillations in the circuit. I admit that one would *naturally expect* the air arc to be equivalent to a gradual, and an arc under oil to an abrupt opening of the circuit. Oscillograph experiments show just the reverse. If a circuit be broken under oil there will be no high potential oscillations called into existence. As Professor Carus-Wilson has pointed out, this is of the greatest moment to engineers who have to deal with

Mr. Field. high-voltage machinery. The correctness of the above statements is beyond dispute, having been established by numerous experiments both in this country and in the States. It shows us at once that all apparatus such as switches, fuses, etc., where an arc can possibly form in air must be avoided in high-tension circuits, whereas oil switches and oil fuses may be used not only with certainty but without engendering the danger of high potential rises. I now wish to touch upon the matter of charging gear for cable networks. A good deal of correspondence has taken place in the electrical papers lately on this subject. It seems to have been the experience of some stations in this country that a main-charging gear is necessary. It is noteworthy that in the States I did not come across a single instance where one was installed. However, I would say, that if any engineer wishes one, let him have it by all means, but let it take the form of an absolutely non-inductive resistance. For this purpose a water resistance is manifestly correct. Anything in the nature of self-inductions, transformers, and the like, should be discarded as highly dangerous. Mr. Partridge has lately described an arrangement used at Deptford consisting of a transformer, the high-tension side of which is placed in series with the cable, and the low-tension side gradually short-circuited through a water resistance. This has apparently given satisfaction, and all I would say about it is, that Deptford has been very fortunate. The type of gear is certainly risky, at certain instants it introduces practically a pure self-induction in series with the capacity. It would appear that the values are such that the combination does not happen to be a dangerous one. We must remember that the Deptford wave form is a very nearly true sine-wave without ripples. If a number of different harmonics existed of any appreciable amplitude, it is clear that with the possible variations of capacity, self-induction, and slight variations of speed, resonance with one or other of the harmonics would be very likely to occur before long. Water resistance mains-charging gear can be made, in fact is made, entirely reliable, simple in operation, comparatively inexpensive, and by proper construction the insulation can be made as high as necessary. It is in fact thoroughly practicable, both mechanically and electrically.

With regard to applying high-voltage tests to cables, in my opinion a mediumly severe test for a long period, say 30 minutes, is preferable to a much higher voltage applied for only a few seconds. If a cable will stand a test for 30 minutes, it is very unlikely that it will be permanently damaged by the strain put upon it. If, however, a very high voltage be applied for five seconds, it is possible permanent damage may be done without actually breaking down the cable. It may stand for five seconds, but break down after ten. This means that deterioration is going on at some spot in the cable during those ten seconds, and consequently considerable deterioration (probably scorching as explained theretofore) may have already taken place at some spots during the first five seconds.

Mr. Atchison's communicated remarks are of great interest. I presume the alternator used was a comparatively small one; I should judge somewhere in the neighbourhood of 5 kilowatts. Resonance

with the fifth harmonic required 27 m.f. capacity—this bears out the contention of the paper that under ordinary central station conditions resonance with low harmonics are not likely to occur, but only with the higher ones. I wish to thank Dr. Thornton and Professor Hay for the references they have given to previous experimental work on the subjects treated in this paper. Mr. Field

Mr. W. B. Hird's remarks have already been answered in this reply. I wish further to thank Dr. Henderson for the table he has worked out and appended, and lastly, to express my appreciation of the generous manner in which my paper has been received and discussed both in Glasgow and London.

The PRESIDENT: Gentlemen, I ask you to accord a most hearty vote of thanks to the authors for their papers. I am sure they have been most interesting in every way, while the discussion we have had has been particularly instructive, and really shows the value of the papers. The President.

The vote was carried by acclamation.

The PRESIDENT reported that the scrutineers announced that the following candidates had been duly elected:—

As Members.

Charles Orme Bastian.	Henry Sherman Loud.

As Associate Members.

Joseph John Perkins Barker.	James Geo. McLean.
Hermann Bohle.	James Mitchell-Cocks.
Frank William Davis.	Thomas Penrose.
John Walter Henry Hawes.	Philip Sydney Saunderson.
Alexander Percy MacAlister.	John Vincent.

Josiah Mower Wallwin.

As Associates.

Edward Coveney.	John H. Pennefeather.

As Students.

Hubert Henry Andrews.	Frederick William Halford.
Isaac Henry Becker.	Richard Pentony.
Randal Eugene Golden.	Kenneth John Thomson.

The Three Hundred and Ninety-third Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday, April 30th, 1903—Mr. ROBERT K. GRAY, President, in the chair.

The Minutes of the Ordinary General Meeting held on April 23, 1903, were read and confirmed.

The names of new candidates for election into the Institution were taken as read, and it was ordered that their names should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

From the class of Associate Members to that of Members—

Randell Howard Fletcher.
John H. C. Hewett.
Gerald Hart Jackson.
Herbert William David Lewis.
Julius Leonard Fox Vogel.

From the class of Associates to that of Associate Members—

John Daniel Dyson.
William Fennell.
Francis William Hewitt.

From the class of Students to that of Associate Members—
Francis Powell Williams.

From the class of Students to that of Associates—
Arthur Blok.

Messrs. R. B. Hungerford and C. J. Phillips were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received from the Museo Civico, Como, and Mr. D. S. Munro; and to the *Building Fund* from Messrs. J. Grant and H. Owen, to whom the thanks of the meeting were duly accorded.

The CHAIRMAN: With reference to these donations, I may mention that the first is from the Museo Civico, of Como, who have sent for our Library a copy of a volume, with an illuminated cover, connected with what has been done by Volta. They also sent us eight copies for distribution at our discretion amongst various Libraries, and to-day the Council decided what should be done in distributing these. I mention this gift specially because it comes from a rather important body, and is a token of their regard for the members of the Institution who recently visited Italy.

I have to announce that the annual conversazione will take place on Tuesday, June 23rd, at the Natural History Museum, and that on June 11th a concert will be given. These dates have been selected because

there will be in London in June the Delegates of the International Telegraph Conference, and it was thought by your Council that it would be proper to give these gentlemen an opportunity of being present at the entertainments.

In front of me you will notice the shield which has been subscribed for by our students, and which is destined to be placed on the tomb of Volta at Camnago. I feel certain the members present will like to examine it; it is a work of art, and was designed for the students by Mr. Gilbert Bayes, a former art student at the Finsbury Technical College, a Gold Medalist of the Royal Academy School, and now instructor in modelling at Finsbury. I may remind you that a replica of this shield was deposited in the Volta Mausoleum, Camnago, by Mr. Hewitt, who represented our students. When the shield is affixed to Volta's tomb, the Museum of Como will be asked to receive the cast, which is now at Camnago. Within the next few days the shield will be forwarded to its destination.

The following paper was then read:—

DIVIDED MULTIPLE SWITCHBOARDS: AN EFFICIENT TELEPHONE SYSTEM FOR THE WORLD'S CAPITALS.

By W. AITKEN, Member.

The designing of an efficient telephone system for one of the great centres of industry requires much careful consideration, as the subject bristles with difficulties. The problem, however, is a most interesting one. Any system proposed must be as simple as possible, consistent with efficiency—quick, direct, reliable.

Before putting my suggestions before you it will be advisable to consider briefly the methods that have already been put forward.

The general practice has been to divide the area to be telephoned into sections, to place in each section an exchange, to connect the various exchanges together by direct junction wires where the traffic is considerable, and to connect the various exchanges or groups of exchanges also to one or more junction centrals, through which connections are obtained to small exchanges where the traffic is not sufficient to warrant direct junctions being run, so that complete intercommunication may be established. Figure 1 shows such an arrangement.

The weak spot of such a system is the multiplicity of junction calls. Only a small proportion of the total calls can be dealt with direct by one operator. In the larger exchanges 50 per cent. of the calls may be local, but in the majority of cases the percentage will be much smaller, in some cases only 5 or 10 per cent. Fifty to 95 per cent. of the calls have, therefore, to be handled by two—in some cases three—operators. The service is not, therefore, ideal. The call has to be passed from exchange to exchange, and a junction call takes about twice as long to complete as a local one,

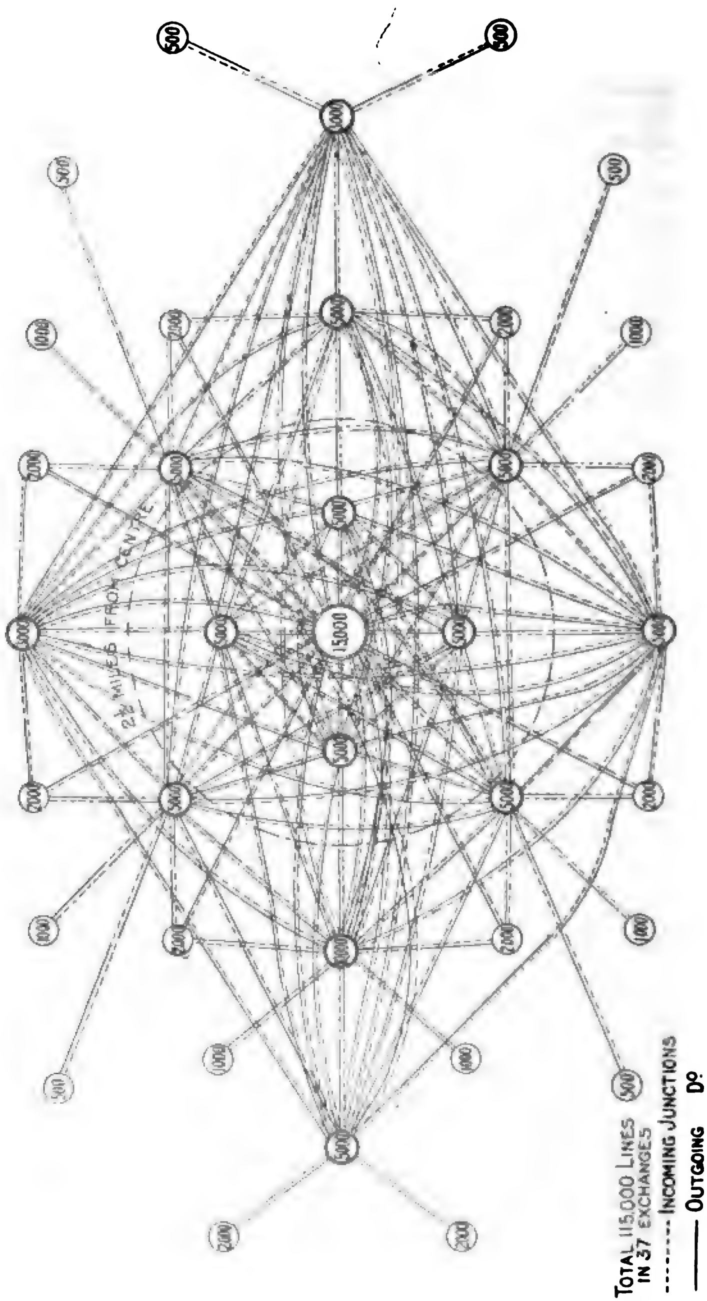

2½ MILES FROM CENTRE
15000
TOTAL 115,000 LINES
IN 37 EXCHANGES
------- INCOMING JUNCTIONS
——— OUTGOING Do

Fig. 1.

The subscriber's number has to be received by more than one operator. There is also the possibility of delay and inefficient transmission because of the complications of the junction circuits and their consequent liability to go out of order. In practice it is found that for an efficient service where there are a considerable number of exchanges, for every 100 subscribers' lines twenty junction lines are required, 10 per cent. for incoming work and 10 per cent. for outgoing work. In addition the junction circuit is much more complicated than a subscriber's circuit ; its apparatus is more intricate and requires more expert handling.

What is recognised as the best method of working junction lines, and used by the National Telephone Company, is as follows :— At the outgoing end the lines are multipled three times on every two sections, so that every operator has every line almost directly in front of her. At the incoming end the junctions are arranged in groups of 25 (average number) per operator and end in plugs, only

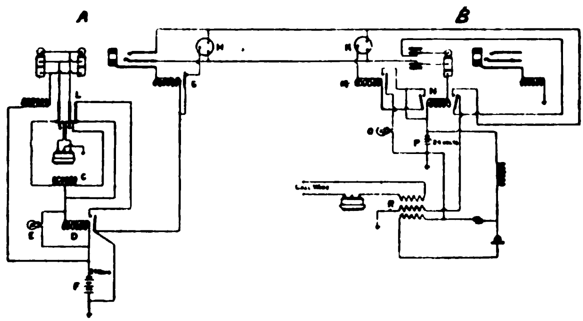


FIG. 2.

signalling apparatus being in addition. A service or order wire is provided per 25 junctions. This at the outgoing end is multipled on every operator's keyboard, and is connected to her telephone by pressing a small push-button. At the incoming end this service wire is connected direct to the operator's receiver. When a subscriber calls, the first-mentioned operator connects with the service wire and informs the listening operator at the other exchange the number wanted, this operator allots the junction to be used as she knows by the position of the plugs what lines are available, tests the line wanted, and, if free, inserts the junction plug, the originating operator at the same time connecting the subscriber to the junction specified. The subscriber may be rung by either the originating or the incoming operator but, preferably, by the latter and automatically. When the clearing signals are received from the subscribers by the originating operator she withdraws the plugs and automatically signals to the incoming end, the operator there then withdrawing the plug also.

The following is a description of two typical junction circuits :—

Relay Ring-through Junctions worked by Call Wire.

Fig. 2 shows the connections of a call wire junction line between two exchanges worked on the above system. This diagram should be considered in connection with Fig. 14.

At the outgoing end A, a local or subscriber's cord circuit is shown, L being the listening key, C the bridging coil, D the 250-ohm clearing relay with lamp E in parallel, and joined up so as to retain when pulled up by battery F.

A single tongued relay G is connected to the bush of the junction jack. The insertion of a calling plug into this jack operates relay G, and thus cuts the earth off the junction lines and bridging coil H.

The operator at the incoming end B obtains an engaged test through the tip of the junction plug and one outer tongue of relay N, on third conductor of the plug, through tertiary winding R of her induction coil. If there is no click she then plugs in, thus operating relay N, which disconnects the tip of the plug from the tertiary winding and connects it direct to the A line; this relay also joins clearing relay M (250 ohms resistance) from the centre point of retardation coil K, direct to earthed battery P.

The jack into which the junction line is plugged is that shown in Fig. 14. When the subscriber at the incoming end depresses his key, the clearing relay D (Fig. 2) at the outgoing end is brought up and retained, thus giving the clear at the outgoing end.

When the outgoing operator withdraws the calling plug from the junction jack, the relay G is released and puts earth on the centre point of the junction line, so that relay M is actuated and the clearing lamp O glows.

When the incoming operator withdraws the plug from the jack, the relay N is released and everything thus returned to the normal condition.

Central Battery Junctions Worked by Call Wire.

Fig. 3 shows the call wire circuit and also the outgoing and incoming ends of a junction. It will be noticed that at the outgoing end no relays are required to join up or cut off the clearing current, as this is already on the lines on the insertion of the plug *q*. (See Fig. 15.) The bush or test connection of the jack has a 30 ohms resistance coil joined in series to earth to complete the circuit for the supervising lamp on the calling plug. The call wire is brought through a key so connected that adjacent positions may be joined together, and terminates on the operator's instrument. A self-restoring indicator relay is also bridged on the line for night use, in the night bell contact of which is joined a lamp, battery and relay for calling when the operator is not listening, a special key being fitted to restore the indicator. In this system also no listening or testing keys are used, these being replaced by a relay C in the third conductor of the cord, and an induction coil with three windings connected so that in the normal position the tip of the plug is joined to the tertiary winding ready to

receive the engaged click, and on the insertion of the plug the relay is actuated and the tip is broken from the induction coil and connected through to the line. This relay is also in circuit with the clearing lamp which is 12 volts and has resistances placed in series with it.

In this circuit a ringing control is used. When the key is depressed

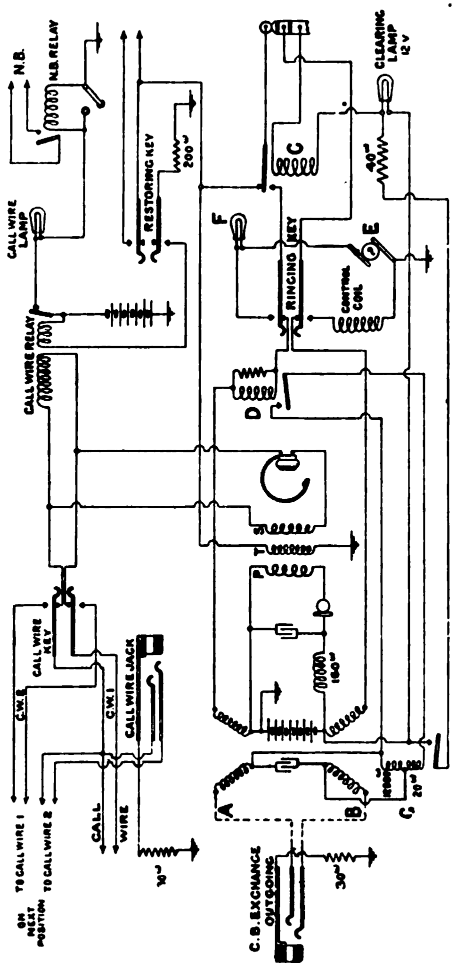


FIG. 3.

a clutch holds it in that position and connects up the ringing generator. When the telephone is taken from its rest an excess of current actuates the electromagnet and releases the clutch, thus cutting off the generator. The only other special point in this circuit is the method employed for clearing, so that on the called subscriber replacing his telephone the clearing signal may be given right back to the calling plug circuit at

the originating exchange, and on this plug being withdrawn the clearing lamp in the incoming junction plug circuit glows.

This is accomplished by means of a special relay G having two windings, one of very high resistance (12,000 ohms), so that the supervising relay on the calling plug at the originating end will not be actuated through it. The other coil is of low resistance to hold up the armature of the relay. This keeps the clearing lamp out by shunting it with a 40-ohm coil. The high resistance coil of relay *g* is short-circuited by the armature of the supervisory relay D in order that the line resistance may be reduced to a minimum, so that the supervisory relay on the calling plug at the outgoing end may be actuated and

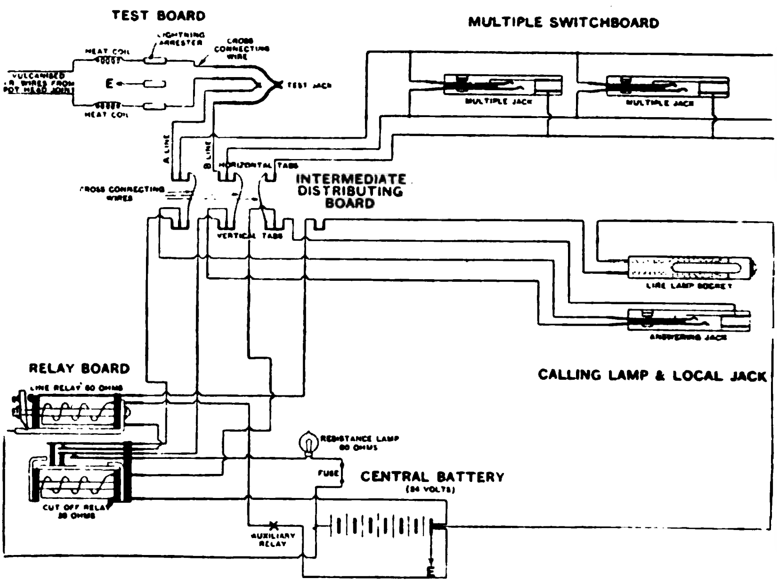


FIG. 4.

so keep the clearing lamp on that plug out while the junction is engaged.

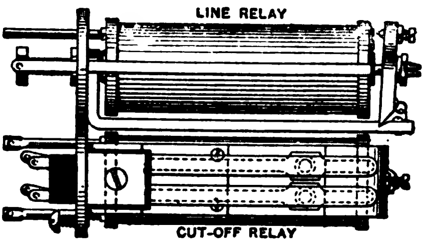
It will thus be seen that when the local subscriber on the incoming junction has finished his conversation and replaces his receiver on the rest, the circuit is broken and the armature of the supervisory relay D falls back, and the high resistance coil of relay G is placed in circuit in the line. This releases the supervisory relay on the calling plug at the originating end and causes the corresponding lamp to glow. The high resistance coil of relay G is, however, during this time still keeping its armature attracted, but on the withdrawal of the calling plug at the outgoing end this is released as the current is cut off, and the lamp glows, giving the signal to clear.

The condenser placed in the line side of the repeating coil is used

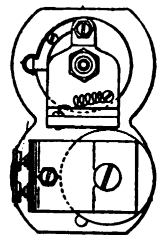
to improve the talking, otherwise the choking effect of relay G would make speech impracticable.

We will just glance for a moment at the circuits of an up-to-date Exchange—on the Common Battery System—so that you may appreciate the slight additional complications which are made necessary by the divided system to be described. Fig. 4 shows the line circuit of the Western Electric Company's system. Fig. 5 shows the line and cut off relays in detail.

In such a system all lines are multipled on every section of switchboard, each containing about 300 subscribers' lines served by three operators. The multiple and answering jacks are branched from opposite sides of the intermediate distributing board. A line and cut off relay is in combination with each line. The subscriber's instrument has a con-



Side Elevation


Front Elevation

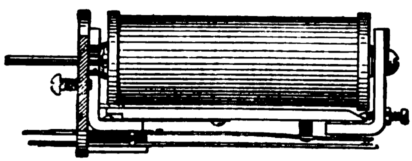

Plan of Lower (Cut-off) Relay

FIG. 5.

denser in circuit with the bell normally, which prevents the central battery discharging. When a call is made by taking the telephone from its rest, a path is provided for the current through the microphone and induction coil, and the line relay is energised. The calling lamp in the local circuit glows, and the operator answers by inserting a plug into the jack hole immediately above the lamp. The cut off relay is then energised and cuts the line relay out of circuit so that the calling lamp ceases to glow. The connection is completed by the insertion of the other plug of the same cord into the multiple jack of the line wanted. A skeleton cord circuit is shown in Fig. 15.

The line and cord circuit of the Kellogg Switchboard and Supply Company are shown in Figs. 6 and 7. The peculiarity of this line circuit is that there are only two wires throughout the switchboard per line instead of three as is usual, and that the lines are not connected to the multiple until the plug is inserted. The cut off relay coil is tapped off the line circuit instead of being on the third wire. The

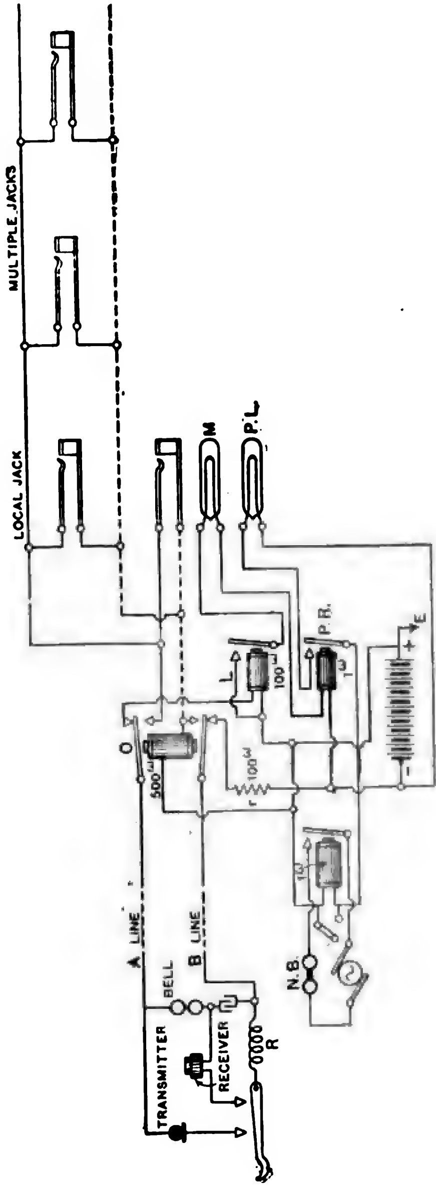


FIG. 6.

NOTE.—The blocks of Figs. 4, 5, 6, 7, 8, were kindly lent by the *Electrician*.

cut off relay is shown in detail on Fig. 8.

Having now considered the general principles of the usual methods of working, let us consider a concrete case, dealing with an area served by two large exchanges.

Such a condition could hardly exist in practice. There would almost certainly be lines to smaller and more distant exchanges. In large systems it is usual to reckon the number of junctions necessary at 20 per cent. of the number of subscribers' lines in an exchange.

In considering the following hypothetical case, I have calculated on 15 per cent. being necessary for working between two large exchanges.

Between two exchanges of 10,000 lines each 15 per cent. of junction lines would be required, 7½ for incoming work to one exchange and 7½ to the other, or 1,500 metallic circuit lines. To accommodate the incoming junctions 20 switchboards (10 in each exchange) would be necessary with 25 lines per operator and three operators' positions per board. Sixty operators and six supervisors are, therefore, required to work the incoming junction lines in the two exchanges, and as each subscriber's operator has a large proportion of connections for the other exchange she cannot attend to so many calls as she could do if all the work were local. On each junction switchboard the complete multiple of 10,000 subscribers' lines must be repeated, and on every subscriber's section 1,125 spring jacks must be multipled for out-going work to the other exchange, these being multipled three times on two sections to place them well within the reach of the operators.

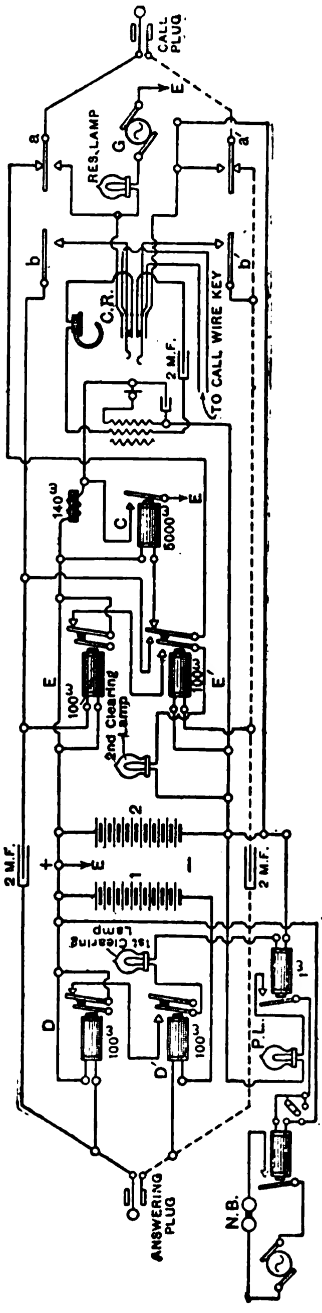


FIG. 7.

The provision of junctions between exchanges is a difficult one, for to provide an ideal service the number of circuits must be sufficient to carry the maximum number of calls at the busiest half-hour of the busiest day, and necessarily many of these junction circuits would be lying idle the greater part of the time.

In the earlier days of telephony there was not much need for the divided board, as the great cities were efficiently telephoned with switchboards having a capacity of from 6,000 to 15,000 lines. When necessary a number of these were fitted and connected by junction lines. Even to-day the system I advocate is worthy of consideration practically only in the world's capitals, where it may be expected that the number of telephone subscribers may reach something like 100,000.

Underground work is essential with the divided board, owing to

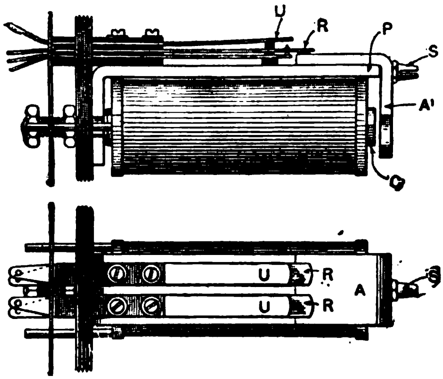


FIG. 8.

earths, etc., giving false calls, and it is only of late years that facilities could be obtained for work of such a nature, and even to-day way-leave facilities are not always obtainable.

It is only in recent years also that satisfactory conduits for large capacities have been introduced, and that hermetically sealed lead-covered air-space paper cables containing a large number of conductors were manufactured. The system I am about to describe to you is just beyond the experimental stage, and I think the time is now ripe for it to receive careful attention.

Such a system must, of necessity, be an underground metallic circuit system. The average length of subscribers' lines would be greater with a divided system than with the junction system, as a larger area would be served from a central, but against this must be placed the great reduction in the number of long junction circuits with their elaborate switchboard equipment.

In my opinion, it is only by adopting a divided multiple switchboard system of working, in which the exchange is divided into several sections, the subscriber having the power to call any one of the sections at will, the large cities of the world may be more efficiently telephoned.

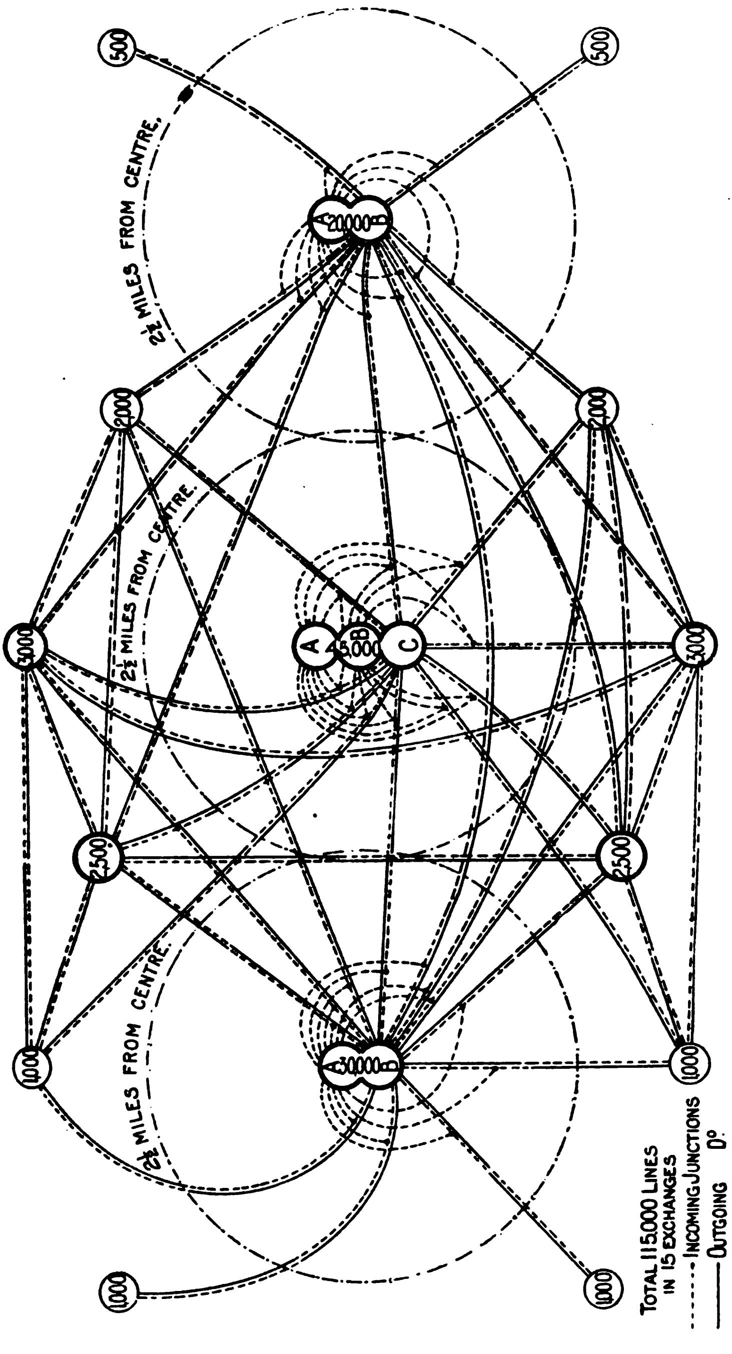

500
500
20,000
2½ MILES FROM CENTRE.
2000
2000
2½ MILES FROM CENTRE.
3000
A
45,000
B
C
3000
2500
2500
2½ MILES FROM CENTRE.
1000
30,000
1000
1000
1000
TOTAL 115,000 LINES
IN 15 EXCHANGES
INCOMING JUNCTIONS
OUTGOING Do.

Fig. 9.

By a divided multiple exchange, I mean an exchange divided into two or more groups, each group having a multiple of a proportion only of the total subscribers' lines, each subscriber having the power of calling each of the groups at will and obtaining connection with the subscribers multipled thereon without the intervention of a second operator. The advocates of the divided multiple board system believe in centralisation and the abolition of junction lines as far as possible. The multiple of each switchboard or division is made as large as can be conveniently reached by the operator, and where those who favour the divided system differ from the advocates of the junction system is in that they ask the co-operation of the subscriber by giving him the selecting of the group of switchboards on which the line wanted is connected. Two or three push-buttons or switches are fitted in combination with the ordinary subscriber's instrument, one, say, labelled 1 to 10,000, the second 10,001 to 20,000, and the third 20,001 to 30,000, or in other suitable divisions. In addition to taking the telephone from the switch-

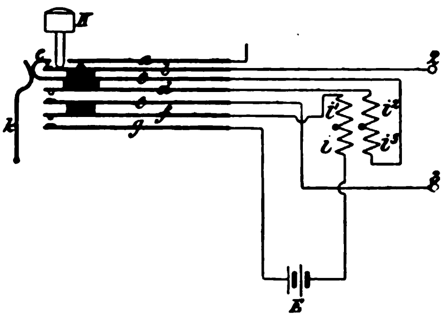


FIG. 10.

hook the subscriber has to press the button of the group in which is the number required; he then gets the connection direct instead of as in the junction system, the first operator having to ask the second to assist her in completing the connection in a large proportion of the calls.

The central exchange on a divided system consists really of two or more great multiple switchboards serving a large area, and its total capacity may be from 30,000 to 60,000 lines, according to the size of the units and number of divisions. Instead, however, of having junction lines between the exchanges the subscriber's line is branched to each division and has a calling signal and answering jack on each, so that it can be connected to each of the multiples of the several divisions, his own line being multipled on one of the divisions so that other lines may be connected to it. The subscriber can, therefore, greatly expedite the rate of operating for a great proportion of his calls, and at the same time he enables the operator to perform more work as a second operator more rarely intervenes.

A proportion of junction working will still exist to the exchanges more distant from the centre, but in most instances it will be possible

to so design a system that 75 per cent. of the possible junction working will be eliminated. I have, therefore, based my estimates on this figure.

Fig. 1 shows a large populous area telephoned on the junction

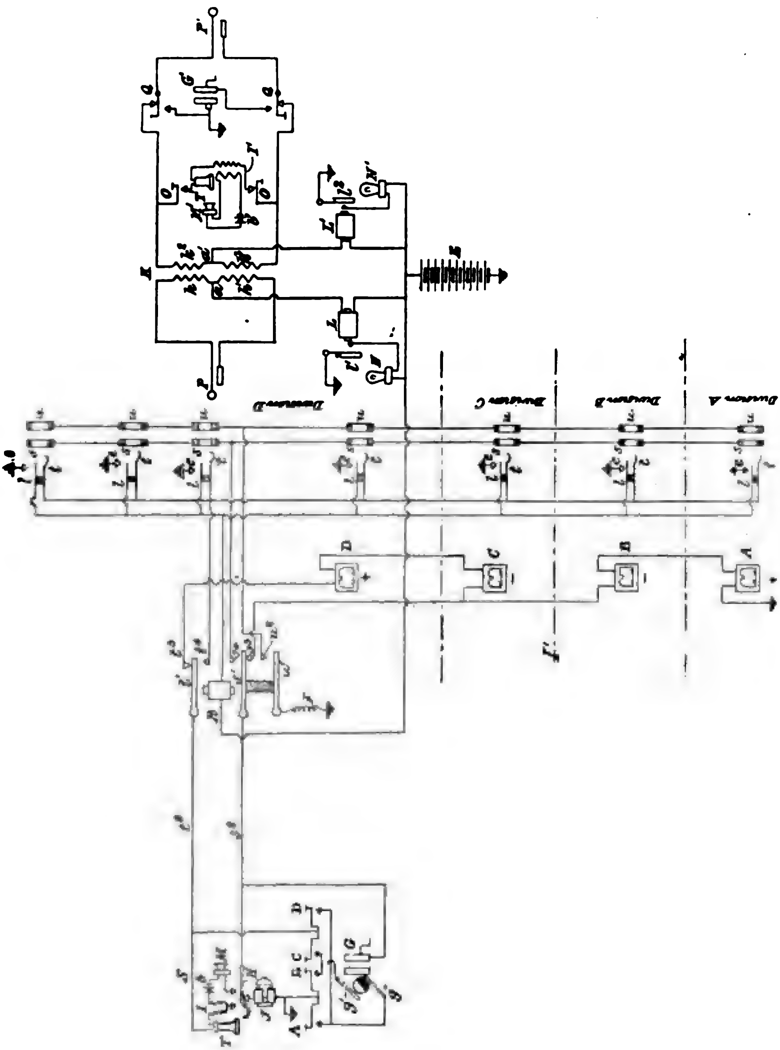


Fig. II.

system, the total number of subscribers being 115,000 in thirty-seven exchanges. The largest exchange has a capacity for 15,000 lines, or 13 per cent. of the total. In the two largest exchanges there is 22 per cent. and in three 26 per cent. Even if the three exchanges were each of 15,000 lines they would only contain 39 per cent. of the whole.

Fig. 9 shows the same area telephoned on the divided multiple system for the same number of lines in fifteen exchanges. The largest exchange has 45,000 lines and the next 30,000 lines. In the former there is 39 per cent., in the two 65 per cent., and in three 83 per cent. of the total.

The lines on the diagrams indicate direction only and not the number of circuits necessary.

I may be accused, with a good deal of justice, of comparing a

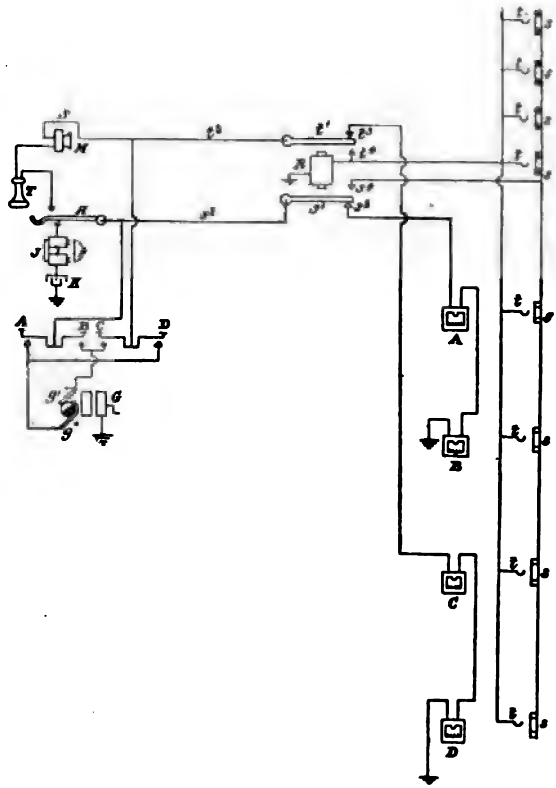


FIG. 12

theoretically good divided system (Fig. 9) with an imperfect junction system (Fig. 1), but with the latter system local conditions and limitations, such as rivers, public parks, low-class residential neighbourhood, etc., form natural boundaries beyond which for the sake of economical working it is not desirable to extend, and therefore single exchanges of the maximum size are not always possible or essential, whereas this does not apply to the same extent to the former.

Milo G. Kellogg, of Chicago, was, I believe, the first to design and advocate a divided multiple board ystem, and a number of exchanges

are now working in America on this plan. Usually two divisions have been adopted, but in one or more cases a four division board has been installed. In these pioneer exchanges the system was complicated by polarised relays and indicators on the switchboards, and at the subscribers' offices by commutated magneto generators.

In at least one case the magneto generators were replaced by the primary speaking battery, acting through an induction coil, giving a "kick" when the circuit was made and broken, sufficient to energise the calling signal (see Fig. 10). Suitable switches connected the current generating apparatus to line in the proper direction to actuate the signalling apparatus in the division required.

In one circuit a positive and a negative polarised indicator are in series across the loop and two similar indicators in series are connected as a tap to earth on one wire of the metallic circuit. (See Fig. 11.)

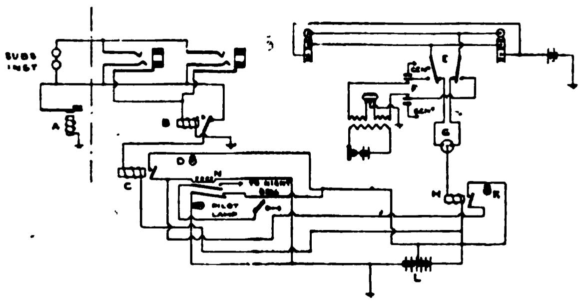


FIG. 13.

In another case a positive and a negative polarised indicator are in series and tapped to earth, two off each line. (See Fig. 12.) Four-division exchanges are thus obtained.

With the development of the central or common battery system of telephone exchange working and the popularising of the telephone the need for a simpler way of working great central exchanges became more urgent, and when considering this question I was struck with the idea of working a divided system from a central battery. I had previously designed two circuits which led naturally up to this, one in February, 1898, with a retaining electromagnet at the subscribers' instrument, which allowed a momentary depression of a key (thereby mechanically completing the circuit of the central battery through the calling relay to earth) to give a permanent signal to the operator (Fig. 13) and another in June, 1899, in which I removed the electromagnet from the subscribers' instrument and provided a local retaining circuit on the relay at the exchange, utilising the ordinary line relay coil for this purpose (Fig. 14).

The latter I preferred to use for my divided board system, as it simplified the apparatus at the substation.

In this system non-polarised relays are used, energised from a central battery when any one of the simple switches at the substation

RING THROUGH SYSTEM

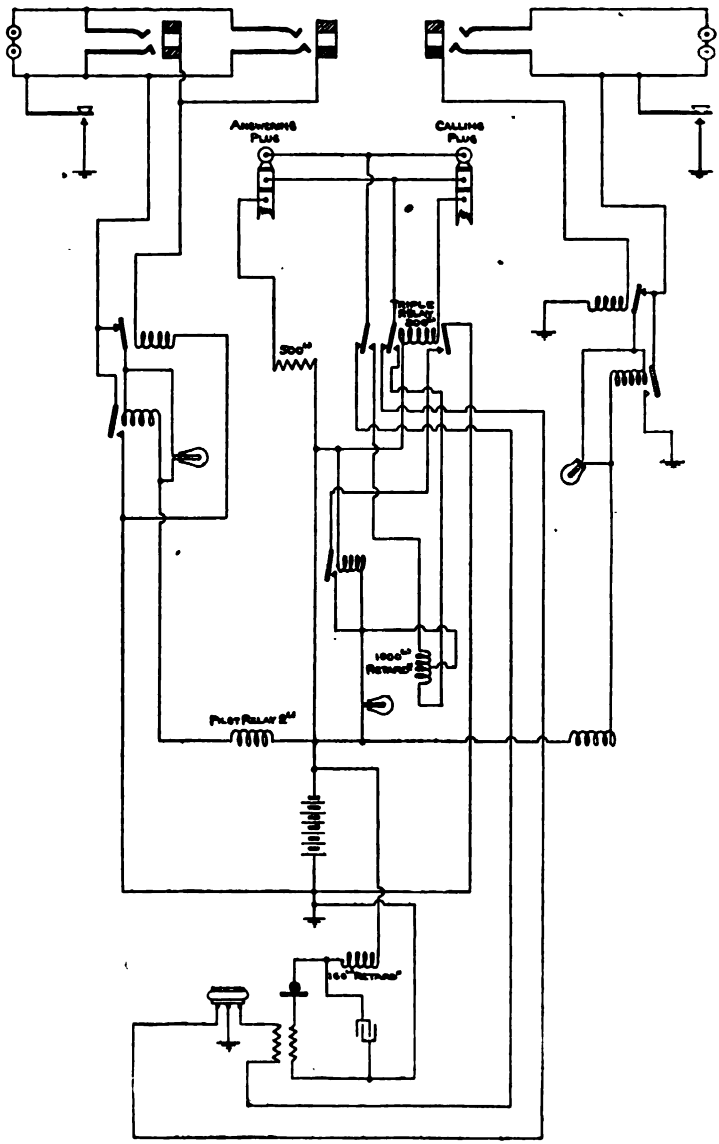


FIG. 14.

instrument is depressed. The caller can thus select any one of two or three groups of multiple switchboards required.

A greater number of combinations could, no doubt, be obtained by step by step movements, but at the expense of simplicity.

In a two-division exchange having two groups of multiple switchboards, two simple single make-and-break relays are necessary at the central and two earthing or grounding switches at the substation.

In a three-division exchange two double (or one triple and one double) make-and-break relays are used in connection with the two wires of the metallic circuit, and in connection with them are three calling lamps, one on each of three groups of multiple switchboards.

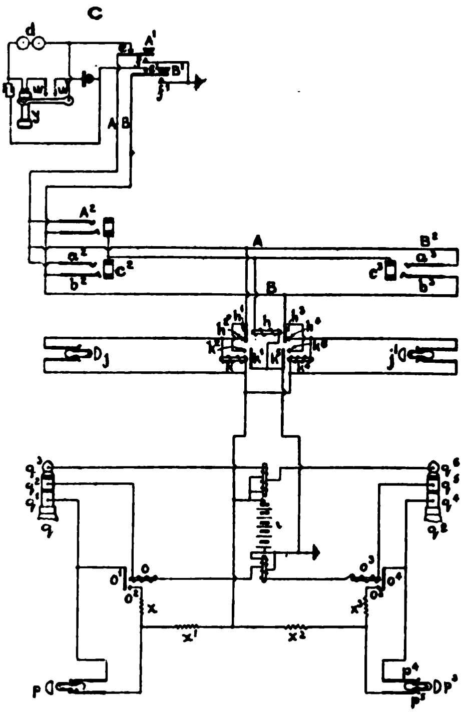


FIG. 15.

Any of the well-known forms of instruments may be used in conjunction with these systems, it being only necessary to fit in combination therewith a simple two- or three-way switch as required, one position earthing the A line, another earthing the B line, and the third earthing the A and B lines simultaneously (the latter in the three-division only). The switch-lever or plunger is put momentarily in one of these positions to give a permanent signal to the attendant at the corresponding switchboard.

With a two-division system, shown in skeleton on Fig. 15 and the line-circuit in more detail on Fig. 16, two switchboards, A^2, B^2 (Fig. 15),

of suitable size are provided, and one-half the total capacity is multipled on one line of boards and half on the other. Each subscriber's instrument has two push-buttons, A^1, B^1, one for earthing the A and the other for earthing the B line.

Each line, after passing through the usual test-board or main distributing frame T.B. (Fig. 16), is connected to a special double intermediate distributing frame, I.D.B. To a central set of soldering tabs the two test-board wires are connected, and from the same set a triple wire per circuit is carried to the multiple jacks, M.J., of one line of boards. From a parallel strip of tabs on one side of the central line tabs a quadruple wire per circuit is carried to the answering jack, A.J.^{1}, and calling lamp, C.L.^{1}, on the same line of boards and from a parallel line of tabs on the other side of the central line tabs another quadruple wire per circuit is carried to an answering jack, A.J.^{2}, and calling lamp, C.L.^{2}, on the second line of board. A quad-cross-connecting wire connects the central line tabs and the tabs on both sides. All wires from the intermediate frames are made up in cables, but the wires between tabs are made in loose quads to allow of ready alteration with the object of changing the local position of any subscriber so as to equalise the work per operator, as in this arrangement it is necessary to allow distribution on each line of boards. Each quad is made up of the two line wires, the test wire and a lamp wire. The test wire also has a connection through the cut-off relay coil to earth. Each line wire has a connection through a tongue and contact of the cut-off relay, C.O.R., and its line relay coil, L.R.^{1} or L.R.^{2}, to battery and earth. Each tongue of the cut-off relay, C.O.R., has also a connection to the tongue of the line relay associated with it, the under-contact of each line relay being connected to earth.

The answering jacks and calling lamps are arranged in the usual way, with pilot relay, P.R., and lamp, P.L., night-bell, N.B., etc., as shown at Fig. 16. The calling lamp has also a connection to the line side of the relay coil, so that it is in parallel with that coil. The action is as follows:—

When a subscriber depresses key A^1 (Fig. 15) there is a circuit from the earthed central battery through line coil of relay, k (with lamp, j, in parallel) associated with that line, through one contact and tongue of cut-off relay, h, through the A wire to earth at key A^1. The line relay, k, is therefore energised and the lamp, j, glows. There is then a local circuit from earthed central battery through line coil, k, and lamp, j, in parallel, through contact and tongue of cut-off relay, h, through tongue and contact of line relay, k, to earth, and the lamp, therefore, continues to glow after the key A^1 is released until the operator answers. This is done by inserting a plug, q, of a connection set into the answering jack, C^2. Another local circuit is then established from earthed central battery, i, through the shunted lamp, p, on the third conductor of the cord to sleeve of plug, q, bush of jack, C^2, over test wire, through cut-off relay coil, h, to earth. The cut-off relay, h, is, therefore, energised and the line relay circuit broken by the tongue leaving the outer contact, so that the calling lamp ceases to glow. The subscriber may then be connected with any other on that

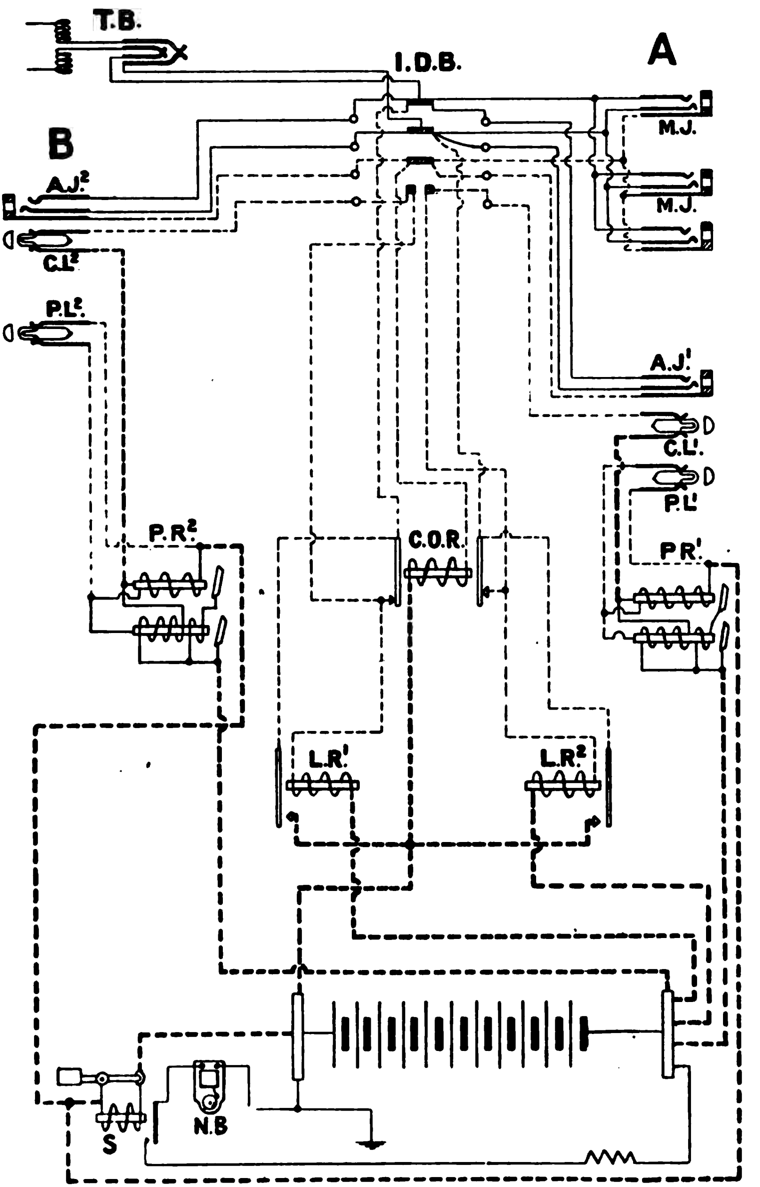


FIG. 16.

multiple. Should the B[1] key be depressed, the other line relay and lamp will be energised, the retaining circuit be broken by the cut-off relay being energised by a connecting set used by an operator at the second line of boards, and a connection completed thereon.

Each operator may have 300 answering jacks and calling lamps under her control, but will only attend to half the total number of calls from each subscriber.

As there are fewer junction lines between exchanges on the divided system, the outgoing junction work will be less and each local operator will therefore be able to attend to a greater number of lines.

Presumably on the junction system about 50 per cent. of the calls would be for the second exchange, and as a junction call takes twice as long to complete as a local one, if most of the work is made local, as on the divided system, the operator will be able to attend to approximately 50 per cent. more lines, so that instead of $66^2/3$ subscribers' sections being necessary on the junction system at 100 lines per operator, only $44^1/3$ sections would be necessary on the divided system.

There will also be a very considerable saving in floor space, and consequently rent or value of premises, as the length of the unnecessary junction and subscribers' sections would be about 270 lineal feet, made up of 20 junction sections and 22 subscribers' sections, each about 6 ft. 6 in. long.

If three 10,000 line exchanges were opened on the junction system then possibly treble the number of junction lines, multiple junction sections, and operators would be necessary, as 1,500 lines are required between A and B, 1,500 between B and C, and 1,500 between A and C, and the subscribers' (or local) operators can each attend to a still smaller number of calls, because a still greater proportion of their work is over junction lines, and each local operator would then be able to attend to a smaller number of lines, say 90 instead of 100. The number of switchboards and number of operators would therefore be increased, while there would be no increase on the three-division system.

With a three-division system, shown in skeleton on Fig. 17 and in detail on Fig. 18, at the central exchange three independent multiple switchboards are fitted, one-third of the total number of lines being multipled on each. Each subscriber's line is multipled on *one* of the three, but has an answering jack and calling lamp (or other indicator) on each. An operator may therefore have 450 calling lamps and answering jacks to attend to—150 in connection with the lines multipled on that group of switchboards and 150 each in connection with the other two groups, so that the subscribers can call and be connected to the other lines that are multipled thereon. Three relays, as before, are required for each circuit, one—the cut-off relay, C.O.R. (Fig. 18)—having two springs which are made to break from two contacts, as before, by the action of the armature when the relay is energised. The coil has one side connected to the earthed side of the central battery and the other side connected to the test circuit of the spring jacks, as is usual. The two line relays differ from those of the two-division board and more nearly resemble the cut-off relay. One has two springs which break from one and make on two contacts when energised, the other has

three springs which break from one and make on two contacts when energised. This modification from Fig. 17 was necessary to get a common circuit from pilot relay, P.R.^{3}.

The coil of each line relay, L.R., has one side connected to the earthed central battery, the other side being connected to the outer contacts of the cut-off relay, C.O.R. The relay tongues or moving springs of the cut-off relay are connected one to each line, each also having parallel extensions to one of the tongues of its respective line relay; these tongues, when the relays are energised, make contact with inner points connected to the earthed side of the central battery. A small incandescent lamp, C.L.^{1}, connected with the No. 1, or A, group of boards is in parallel with the coil of one-line relay, L.R.^{2}, and a second lamp, C.L.^{2}, in connection with the No. 2, or B, group of boards, in parallel with the coil of the other line relay, L.R.^{1}. The line relays

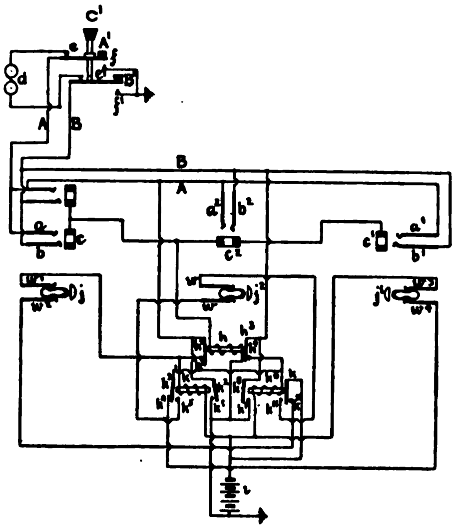


FIG. 17.

have another tongue, which rests normally against an outer contact, but when actuated by the armature when the relay is energised breaks from this point and makes contact with another. Normally the circuit of the A and B lamps are completed through these contacts. When, however, the relay L.R.^{2} immediately associated with the A group of boards is energised the circuit of the B lamp C.L.^{2} is cut; similarly, when the B relay L.R.^{1} is energised the A lamp C.L.^{1} circuit is cut and if, therefore, both relays be energised at the same time the circuits of both lamps will be cut. The circuit of the lamp C.L.^{3} in connection with the No. 3, or C, group of boards is then established, the circuit then being from the earthed central battery through pilot relay, P.R.^{3}, through the tongue and inner contact of the line relay, L.R.^{2}, through I.D.B., through the C lamp to the inner contact and tongue of the line

relay, L.R.[1], through the right-hand outer contact and tongue of the cut-off relay, C.O.R., and the other tongue and under-contact of the line relay L.R.[2] to earthed side of battery.

Samples of suitable relays are on the table. With modern improvements the dread of double and triple contact relays has disappeared.

At the substation three push-buttons are fitted (Fig. 17), and, according to the number required, the subscriber presses the A[1], B[1], or C[1] key. When the A[1] or B[1] key is depressed the A or B calling lamp glows, as described for the two-division arrangement, and when the C[1] key is depressed both lines are earthed and both line relays are energised, the circuit of the A and B line lamps is cut and the lamp associated with the third, or C, group of boards glows. When an answering plug is inserted the cut-off relay is energised and the local retaining circuits are broken and the C lamp ceases to glow.

The foregoing arrangement can be used practically with any cord circuit. The following are a few examples. In the ring-through cord circuit (Fig. 2) the cord is bridged by a suitable differential retardation coil C, having its centre point connected through the coils of a relay D, to the earthed central battery, a lamp E being in parallel with this coil. The side of the relay coil farthest from the battery should be connected to the contact of the relay, the tongue connected through a spring and contact of the listening key L to earth, so arranged that the relay circuit may be broken in the listening position. When a connection is made and any one of the plungers at the substation is depressed momentarily the armature of the relay is attracted and a local circuit established which retains the armature, and therefore the clearing lamp glows until the operator brings the key to the listening position or withdraws the plug.

This arrangement may be used in conjunction with the ring-through, system, in which one subscriber rings the bell of the subscriber wanted or the operator may do the ringing. In the former case a generator is supplied with each instrument, in the latter case this is not necessary.

In the ring-through system with relay and lamp which was designed to replace the now practically obsolete call-wire system I preferably use a cord circuit without listening key as shown on Fig. 14.

The operator's telephone is normally in circuit through the back contacts of a triple relay in the third conductor of the calling cord. The operator is therefore ready to answer immediately she inserts the answering plug, but when the connection is completed by the insertion of the second plug her telephone is automatically cut out, as a local circuit is completed from earthed battery, through coil of triple relay, through sleeve of plug, bush of jack, over-test wire, through coil of cut-off relay to earth.

This combination, it is believed, will form the simplest manually operated switchboard known. The operating is as follows:—

(*a*) When the lamp glows operator inserts answering plug.
(*b*) Tests line wanted, and if free inserts plug into jack of line wanted.
(*c*) When clearing lamp glows she withdraws plugs.

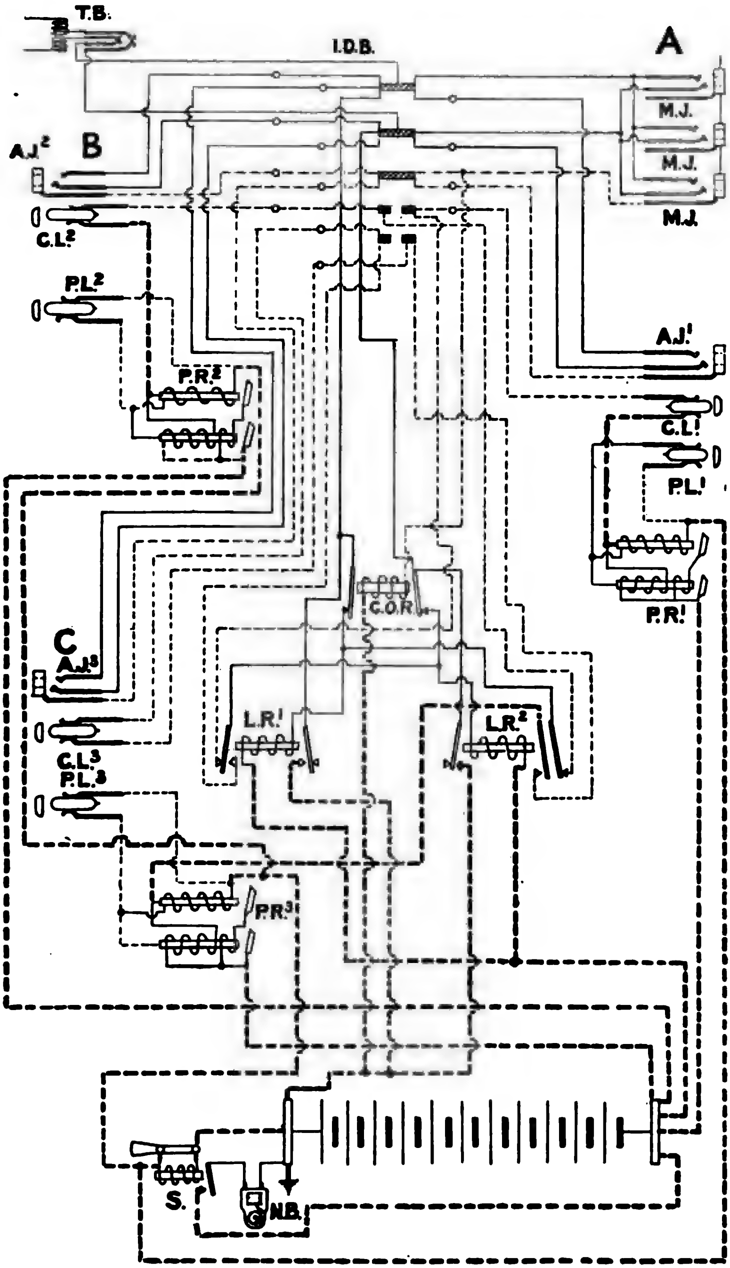

T.B.
I.D.B.
A
M.J.
M.J.
M.J.
A.J.2
B
C.L.2
P.L.2
P.R.2
A.J.1
C.L.1
P.L.1
P.R.1
C.O.R.
C
A.J.3
C.L.3
P.L.3
L.R.1
L.R.2
P.R.3
S.
N.B.

FIG. 18.

Such a system, up to the present, has only been proposed with central battery signalling, a primary battery at the subscriber's being used for speaking.

The divided board system will work also most efficiently with the Western Electric Company's common battery cord circuit when automatic clearing on two lamps and speaking from central battery are obtained. (Fig. 15.)

With the circuits of the Kellogg Switchboard and Supply Co., Fig. 7 it will also work excellently; in fact, this company have specially laid themselves out for building large exchanges on this system. Their circuits have only two wires in the multiple and two-way plugs, and they have, therefore, been able to reduce the size of their standard spring jacks to three-tenths of an inch face measurement instead of the ⅜ in. as is usual, and I believe they are now manufacturing switchboards of 20,000 capacity per division.

I would propose forming one huge central exchange of from 30,000 to 60,000 lines in the heart of each great city, this exchange serving an area of about 14 square miles; this, of course, would vary with the density of the population, and the prospective number of renters. With an underground system, and cables containing from 250 to 300 pairs each, such an arrangement is perfectly feasible. Four main conduits should radiate from the central building, each containing from 50 to 80 ducts, these branching out, as required, up to a distance of from 2 to 2½ miles from the exchange. Outside this area, say at 3½ miles' distance from the central, subsidiary exchanges should be formed. When these exchanges are of considerable size they would have direct junction lines to the central, and incoming junction sections on each of the three multiples of the central exchange; where, however, the junction lines were few the operator would call the multiple required at the central by pressing the corresponding key in the same way as a subscriber.

The outgoing junctions for these subsidiary exchanges would only be multipled over one group of boards at the central, say the C group, so that subscribers would call, say, numbers 1 to 16,000 by depressing the A key, 16,001 to 32,000 by depressing the B key, and 32,001 to 45,000 and all subsidiary exchanges by depressing the C key. These numbers of lines can perfectly well be placed within the reach of the operators by using for the A and B multiples 6 feet 3 inch frames having 9 panels of strips of 20 spring jacks measuring 8¼ inches by ⅜ inch. Eighteen blocks of 100 jacks give a height of about 2 feet 9¾ inches. The answering jacks and calling lamps and number pegs, in strips of 20, with space sufficient for 533 lines per operator (this being about equal to 177 lines on a simple multiple, as each operator only attends to one-third of the total number of subscribers' calls on a three-division system) would occupy a height of about 11¼ inches, so that the height of the upper row of spring jacks above the keyboard would be about 3 feet 9 inches.

The C line of boards could either be made to accommodate a slightly smaller number of subscribers' lines, so as to leave room for the outgoing junctions, or the section could be still further increased in length.

For a 45,000 line three-division exchange, reckoning that each operator can attend to an average of 150 lines per multiple board, or a total of 450 lines, the A and B groups would each consist of 107 multiple sections; while reckoning that each operator at the C group could attend to 100 lines only owing to the amount of junction work, 130 sections would be necessary.

Each group of switchboards (and possibly also separate intermediate and main distributing frames) should preferably be in a separate fireproof room in practically separate buildings, so that in case of fire the fireproof doors between could be closed and so confine the breakdown to one group.

The premises should, therefore, consist of one central building with flanking wings. In the basement of the central building one main distributing frame should be fitted, arranged radially in four sections of 12,000 or 15,000 in the shape of a Greek cross, the four conduits opening out at the ends. On the ground floor should be similarly arranged the intermediate distributing board and relay racks, the former having two or three distributing fields, as it may be necessary for equalising purposes to cross-connect the lines on one group of boards and not on the other. In the central building might be the C switch room, the A and B switch rooms being in the right and left wings respectively. Preferably the groups or divisions of the exchange should grow uniformly, as will be made clear by the following example. If it is desired to convert a 9,000-line ordinary exchange into a two-division exchange, and it is necessary to begin the second group with a capacity of 2,000 lines, then whilst it is only necessary to provide 2,000 extensions of answering jacks and lamps on the 9,000-line frame, for which there is plenty of room, the 9,000 lines require lamps and jack extensions on the sections built for 2,000, and each operator would have an abnormal number of lamps and jacks from the first line in front of her, and these would require to be redistributed when further extensions were made.

I think it must be granted, from what I have said that, from an operating point of view a great boon would be obtained by the introduction of the Divided Multiple Board System. Also that the made-up or speaking circuits would be much simpler.

As far as I can see the principal objection that can be urged against it is that the system depends for its efficient working upon the co-operation of the subscribers. We have been told that "men are mostly fools." Must this be taken literally? I think at any rate, not sufficiently fools to spoil a divided system by wilfully or carelessly calling on the wrong group or division of the exchange.

COMPARATIVE ESTIMATE OF EQUIPMENT NECESSARY FOR TWO 15,000-LINE EXCHANGES CONNECTED BY JUNCTIONS AND ONE 30,000-LINE TWO-DIVISION EXCHANGE.

Apparatus for two 15,000-line Exchanges.	Description of the Apparatus.	Apparatus for a 30,000-line Exchange.
30	Incoming junction sections (at 7½ %)	None
100	Subscribers' sections	66⅔
1,950,000	Multiple spring jacks	1,000,000
337,500 yds.	63 wire cable (30 yds. I.D.B.) ...	195,000
168,750	Outgoing junction jacks	None
40,500 yds.	33 wire cable	"
30,000	Answering jacks	60,000
30,000	Calling lamps	60,000
30,000	Double cut-off relays	30,000
30,000	Line relays	60,000
175,500 yds. (1,500 lengths at 117 yds.)	84 wire cable	198,000 (3,000 lengths × 66 yds.)
2,250	M.C. junctions × length X ...	None
2,250	Repeater coils for junctions ...	"
2,250	Condensers for junctions	"
2,250	Relays (12,000 ohm + 20 ohm) ...	"
2,250	Relays (local clearing)	"
2,250	Relays (on third conductors) ...	"
2,250	Clearing lamps	"
2,250	40-ohm resistance coils	"
2,250	30-ohm resistance coils	"
90	Call wires between Exchanges with equipment	"
2	Lines of tabs on I.D.B.	3
1	Cross connecting wire per line ...	2
	Twin switches on instruments ...	30,000
390	Operators	200
39	Supervisors	20
845 ft.	Length of switchboard ... ... (Practically the two-division equipment can be fitted in a building necessary for one of the 15,000-line Exchanges, and therefore there would be a great saving in cost or rent of buildings.)	433 ft. 4 in.
	Increased length of lines ... ... (If the 2,340 junctions and call-wires were each two miles long, this would be equal to an average increase in the length of each of the additional 15,000 lines of 550 yards.)	X × 15,000
	Mileage of wire saved in the two-division Exchange ... ... (This used outside would increase the average as above to about 880 yards.)	5,707
75	Value of service	100
2	Power Plant with maintenance ... (Great economy will be effected by using one large Power Plant instead of two smaller ones.)	1
2	Power Board Staff	1
2	Engineers-in-charge	1

TABLE OF CONTENTS.

References.

Patent No. 4699, March 25, 1890. M. G. Kellogg.
Patent No. 5,928, March 30, 1900. W. Aitken.
Patent No. 10,124, June 1, 1900. J. E. Kingsbury.
Patent No. 18,031, October 18, 1900. Milo G. Kellogg.

Mr. Laws Webb.

Mr. Herbert Laws Webb : I have read Mr. Aitken's paper with a great deal of interest. The telephoning of very large cities is a subject which, of course, telephone engineers look at as a daily increasing problem. I am quite sure that all telephone men must admire the ingenious manner in which Mr. Aitken has worked out the circuits of the divided multiple system to adapt them to common battery working. However, on the broad lines of the problem my opinion is that it is working in the wrong direction to advocate divided multiple exchanges. In the first place, such a system largely increases the line plant. It must necessarily greatly increase your average length of subscribers' line if you divide your city up into very large districts, and I think it will be found in all large telephone systems that the line plant represents by far the greater proportion of the cost of the whole plant. I think even where line costs are the cheapest the percentage of cost of the line plant is about 60 per cent. of the cost of the whole system, and to save in the exchange plant, which is the smaller item of cost, and increase in the line plant, seems to me to be working in the wrong direction as far as cost is concerned. I think in very large cities, where it is well known that the expense of building underground lines is much greater than in smaller places, that would bar out the divided multiple board altogether on the question of capital cost. The other point that seems to me to be very largely inadvisable with this system is that it puts back the operating of the service into the hands of the subscriber. With the common battery we have practically taken the operation of the service entirely out of the hands of the subscriber. The subscriber has the simplest action to perform ; lifting the telephone off the support, which he must do in order to use it, automatically gives the calling signal, and in replacing the telephone, which I suppose 999 out of 1,000 do properly, he automatically gives the signal to disconnect. That gives us undoubtedly the cleanest, the quickest, and the simplest service that it is possible to give. In all systems where part of the operating is done by the subscriber there are numerous troubles due to the subscriber's lack of proper care in operating. If you put these two or three buttons on every instrument for the subscriber to press according

Mr. Laws Webb.

to whether he wants one number or another, in very many cases he will press the wrong button and get the wrong operator. Then you may expect something like this to happen : the subscriber gives the number that he wants, and the operator says, "You have pressed the wrong button." He says, "What?" Then the operator gets a little more impatient, and says rather shortly, "You-have-pressed-the-wrong-button!" And the subscriber says, "Hang your buttons! Why can't you give me my number?" In a great many cases that is bound to be what would happen, more or less. The language in some cases would be worse, and in other cases it would be better. Consider, for instance, one of Mr. Aitken's proposed world's capitals systems of 115,000 subscribers. You would have an average daily traffic there, at flat rates, of well over one million calls. All of those million calls would not come from expert subscribers. It is not always the man who signs the contract who uses the telephone; it is used by all sorts of people, from the office boy down—or up, according to which way you look at it—and it is used very largely by strangers. Every world's capital always has a large floating population, and if you have 115,000 telephone stations you would have a large number of public stations, so that a large proportion of your daily traffic would be from people who are not expert in using that particular system. Therefore a pretty fair percentage of your million calls a day would be calls that would be sent in wrongly. That would give trouble; that would need extra attention, unprofitable work on the part of the operators and the supervisors and the rest of the exchange staff. I do not think that you can plan out any telephone system nowadays—we have learnt something of late years of the telephone-using public—without keeping a very careful eye on the public and on what it does with the telephone at the public end of the system.

There are one or two points that occur to me in Mr. Aitken's estimates of operating values. I noted somewhere that he reckons a junction call as being the equivalent in time of two local calls. That seems to me quite excessive—that it should take twice as long to operate a junction call as a local call completed at the same switchboard. The experience in New York, which for the past eighteen months or so has had uniform common battery working, is that the difference in time between completing a local call and a junction call is nothing like so much as that. The very careful tests made of a large number of connections, and tabulated with great care, show that the actual time is 23 seconds odd for a local call and 30 seconds for a junction call. There is almost exactly 7 seconds difference between them. That is, a junction call does not take longer than ⅓ more than the local call. That, of course, gets rid of a good deal of the argument in favour of the divided multiple board. If your junction call does not take longer than 30 seconds to operate, there is not a very strong argument against junction working. As a matter of fact, having the relay system in use uniformly, so that all the exchanges are worked on the same system, and all the operators are trained to do the same class of work exactly, there is practically very little difference between the completion of a local call and a junction call.

Mr. Laws Webb. The question of handling very large numbers of subscribers has been solved in New York a good deal in this way, that a large number of what you might call satellite exchanges have sprung up owing to the use by subscribers of what we call private branch exchanges, the private branch exchange simply consisting of a miniature exchange—it often grows to be a pretty large one—on the premises of the subscriber. That class of service was at first introduced to give a good service to very busy subscribers. We found that a great many subscribers were over-using their lines, and were blocking their lines entirely to the inward calls. We persuaded those very busy firms to take a branch exchange outfit consisting of a switchboard connected by a number of trunks to the nearest exchange, and from the switchboard were extended instruments to the different departments and offices of the people who had to use the service. A trained operator was put at the switchboard, and the whole service of that subscriber was handled through that private branch switchboard. At first it was pretty difficult to get business concerns to take up that class of service: it cost more, and they did not see why they should not use a telephone in the old way, that is, working one flat rate line so that it was used almost exclusively for outward calls and gave the inward traffic no chance at all. However, that private exchange system gave so much improved a service, and handled the traffic of a busy subscriber so effectively, that it very soon became popular, and now instead of having to push it by means of canvassing, and so on, it has become the accepted thing, and there are actually in New York in private employ, operating branch exchange switchboards, about twice as many trained operators as there are in the main telephone exchanges themselves. There are, I should think, at a rough guess—I have not got the exact figures in my mind—approximately 30,000 stations out of 100,000 stations in New York that are operated on private branch exchanges. That method of working the telephone service undoubtedly largely helps us to solve the question of dealing with very large numbers of subscribers. Where you have big establishments, such as large hotels and large apartment houses, it gives an admirable service, and it of course largely saves in the number of lines required to serve a given number of telephone users. It is the practice now in New York to build no large apartment house or large hotel without putting in a private branch exchange with a telephone in every apartment, and I think, in fact, the New York Telephone Company has contracts for private branch exchanges to be equipped in hotels that are not even yet built, so thoroughly is the use of the telephone recognised in New York.

Mr. Gill. Mr. FRANK GILL: Mr. Aitken's paper is somewhat unusual in that, instead of propounding a definite problem of known factors, he gives a somewhat speculative paper. But I do not think it is any less important on that account, because it deals with a very large and difficult subject, and even on the "cheap and nasty" plan his 115,000 subscribers involves figures running into some millions. I should like to congratulate Mr. Aitken on the ability he has shown in handling his subject. For reasons which are fairly obvious I prefer not to express any very strong opinion one way or the other, but I desire to point out one or

two things which should be borne in mind by telephone engineers who contemplate putting in a divided board. In the first place I understand there are only two divided boards in existence, one in St. Louis and one in Cleveland, each for 20,000 lines. One most important factor which comes in is time. Every telephone subscriber wants to get through almost before he makes his request, and I doubt very much whether there is anything in the commercial world or in the scientific world which is cut quite so fine as ordinary telephone operating. The first query which comes is this, I rather want to apologise to the Institution for trying to introduce a new factor; we have such a lot of factors that one hesitates to bring in another one, namely, the time-factor. The time-factor of a subscriber's line is, we know, roughly about 2·28 per cent.; the time-factor of a junction line—or, as they call it in New York, a trunk line—is about 23·5 per cent. That immediately raises the very important fact that, if you are going to extend copper, you extend copper which will be used in one ratio or in the other. In Mr. Aitken's Fig. 1, I have assumed, taking out figures as far as I could without knowing the conditions of the locality in which the exchange was to be planted, that there would be 115,000 lines, which would equal about 70,000 miles of metallic circuit; there would be, in addition, about 60,000 miles of metallic circuit for junctions. In Fig. 9, I make out there would be something like 172,000 miles of metallic circuit for subscribers' lines, and about 14,000 miles for junctions, a very considerable reduction. The difference, therefore, is 56,000 miles of metallic circuit against Fig. 9, which is approximately about 1,000 tons of copper. Perhaps telephone men will follow the point a little easier if I say 183 miles of 306 pair cable. It is a serious item, which you must consider, and see whether what you get is worth it. On the intermediate distributing board there would be three divisions, two of them extra. There would be probably something like 123 tons more of copper on those two. The jumpers for the two divisions would be extra. There would be also a whole lot of smaller details. The intermediate boards would be each full size, and the main frame would be larger. The line lamps, the line relays, fitted with a back contact in a doubtful situation, would be more—I am sorry Mr. Swinburne has gone, because I wanted to tell him that we no longer wind electromagnets with german-silver wire, if indeed it was ever done—there would be also the keys on the instruments. Against these items—I have not noted them because Mr. Aitken has covered them very fully—there would undoubtedly be a large number of savings. Mr. Webb has rather anticipated me in regard to the question of the ratio of junction calls. In the paper (page 814) a problem is worked out which is based on the ration of 1 : 2. I make out that if one takes the ratio as 1 : 1·3, instead of requiring 66 ⅔ sections one will only require 51 ⅔ sections. The distribution on a divided board is much more difficult, because you have to distribute each section of the intermediate board separately. In calculating the average numerical chances of junction working, in Fig. 1 we have 97 per cent.—that is, the chances of the call being an outgoing call—and in Fig. 9, 89 per cent.; but, of course, you have to consider the direction of the traffic. Mr. Gill.

Mr. Gill.

I would conclude by one suggestion, that if, as I have endeavoured to show, the length of the subscribers' line in a divided board system is a serious item, and one which requires to be considered carefully, then the same item also requires grave consideration in any attempt made to bring two exchanges together in one building, where one gets all the junction work and none of the advantages of the divided board.

Mr. Harrison.

Mr. H. H. HARRISON: I have been very interested in the paper which has been read, as the question of the adoption of divided multiple boards interested me some five or six years ago, before Mr. Kellogg brought out his important patent. Mr. Aitken seems to have assumed that we all know the necessity for divided boards. Briefly, it is, of course, that, as the number of subscribers goes up, the multiple connections, or panel area, required to enable the operator to communicate with any subscriber become so great that it is no

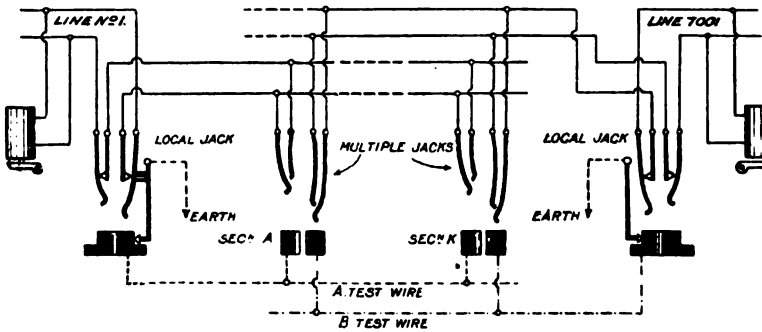


FIG. A.

longer possible for one operator to complete the connection. Hence this gave rise over the other side to what was called, I believe, the "express" system. That consisted of two boards—one in which the calls were received, and the other board, or B board, as it was called, in which the connection required was effected. This, in turn, necessitated call-wires between the boards and two operators for every connection made. The divided board system, as described, is very ingeniously worked out, but I think it might be found rather difficult in practice. For instance, it is pretty certain that the number of divisions would have to be limited to four, because with an ordinary metallic loop no simple system of selective signalling is possible in more than four ways; and while I do not think it is too much to ask a subscriber to select one of four buttons, any more than it is asking too much of him to look up the number of the required subscriber in his telephone directory, he might reply, if you ask him to make combinations with four buttons—the telephone subscriber is rather an impolite person—that he was not having any; so it is pretty certain, therefore, that that limits the number of divisions to four. I would point out that the excellence of Mr. Aitken's divided board service might be such that in course of time he would have each one of his four boards

beginning to grow unwieldy, as the early multiple boards did, and then he would be in the same difficulty as the early telephone people were. I therefore want to describe a system called the Duplex Multiple Board, which was invented over the other side, I believe, one exchange of which was worked on the system. As it requires a diagram to adequately describe it, I will ask your permission to communicate the rest of my remarks. Mr. Harrison.

(*Communicated.*) In the duplex multiple system the subscribers are divided into two groups, A and B. Each line terminates in a local jack in the usual manner. The multiple jacks are of special construction. They consist, as shown in the diagram, Fig. A, of two pairs of line springs to which the A and B lines are connected respectively, and the bushes are split to form the necessary testing circuits.

It is claimed for this board that its capacity can be increased to double that of the ordinary type, the multiple area remaining the same. It has, however, two serious disadvantages. Three plugs are required, an ordinary answering plug and an A and a B plug; further, care is required in testing for the engaged signal to see that the right half of the bush is touched.

It is, however, an interesting attempt to reduce the number of the junction lines by increasing the capacity of the central exchange without, at the same time, requiring a system of selective signalling.

Mr. J. E. KINGSBURY: I should rather have preferred, sir, that somebody having more confidence in Mr. Aitken's system than I have should have spoken at this stage, in order that he might have had some of the support which I feel he deserves, if only for bringing such a paper before us. We have lacked telephone papers, and are therefore very much indebted to him for the one which he has read. I think, however, there is some danger of our taking his paper too seriously. I am not at all sure that Mr. Aitken has not brought this paper before us as something for discussion, rather than for us to assume that he is prepared to take the responsibility of the adoption of the system he proposes in one of the world's capitals. I believe the system has not yet been put into operation. It is something, therefore, of an experiment; and one of the world's capitals is the last place in the world where any responsible telephone engineer would think of trying experiments. For that reason I think we need not, as I say, consider it altogether too seriously. But we must recognise the fact that in the development of the telephone growth which must come we shall need all the invention that we can get, and it is even possible we may have to call upon the public to do what Mr. Aitken is perfectly ready to allow them to do. But before we do that I feel that we must exhaust many other sources of invention that we have not yet touched. Let us consider what it is that Mr. Aitken proposes. He proposes that we shall have a series of switchboards, on each of which a portion of the jacks shall be multipled. We can get a better mental conception of the arrangement if we assume a series of boards painted different colours; we will call them red, white, and blue. Upon each of them is a signal, which may be operated at the will of the subscriber by pressing a selected button; and under such circumstances we should Mr. Kingsbury.

Mr. Kingsbury.

naturally make the buttons a series of similar colours. Press a red button and you drop a signal on the red board, and so on. That is what is called "selective signalling." We had such a system in connection with the "ring through" system, adopted by Mr. Poole in the early days at Manchester. There was one kind of indicator which would drop by pressing a white button, and another kind of indicator, a clearing indicator, which would drop by pressing a black button. In those days there was only one line, but both poles of the battery were utilised, one by the white button and the other by the black. On the introduction of the magneto there was a somewhat similar use of a single line, by sending an alternating current on one occasion and a commutated current on another. That gave us an opportunity by magneto working of selecting either one of the two signals. The introduction of metallic circuit working and central battery working gave us an opportunity of four choices, and really there is very little reason why, since a four party line is an easy thing to operate, a four area system should not be utilised, working on the common battery. Of course it involves a large quantity of abstruse diagrams and a large amount of technical ability to work them out, but in essence that is what it amounts to. Mr. Aitken has gone into the question of comparative costs. I do not propose to follow that in any detail; it has already been done by other speakers. But I would like to emphasise Mr. Webb's remarks in regard to the operation of the system by the public. I anticipate that Mr. Aitken will consider that his reliability on the public is not so misplaced as some of us think. My impression is that a telephone engineer regards his subscribers individually as not only men of very great sense and ability, but I am not at all sure whether he does not consider them all Senior Wranglers. The police regard the individuals of society as most law-abiding people, but they have a method of dealing with crowds which leaves the individual, and the law-abiding character of the individual, out of account. The telephone engineer, in dealing with the public, has to adopt a similar distinction between individuals and telephone subscribers. It is perfectly useless for us to depend upon a member of the public—perhaps an impatient man of business, whose telephone call may mean thousands of pounds—to press the right button or do the right thing at all unless it is absolutely the most simple thing. For that reason alone I think Mr. Aitken's method of a divided board cannot be expected to be put into operation until, as I say, other methods have been exhausted. Why does Mr. Aitken suggest the divided board? Mr. Kellogg suggested it probably ten years ago. He suggested it when the limitation of the multiple board was about 6,000; to-day it is 20,000, to-morrow it will be 30,000; and I see no reason to assume that we should regard that number as in any way within reach of the limit. All we can say at present is that the multiple board has grown in its capacity with the requirements of the business. I see no reason at all why we should assume that its progress has stopped, and I think we may take it that in that direction inventive ingenuity would be well displayed.

Mr. Gavey.

Mr. J. Gavey: Sir, I think Mr. Aitken has placed the Institution

under a debt of gratitude for having brought this very important matter before it to-night. Many of the speakers who have preceded me have made remarks which in some cases have anticipated my own. In reference to certain criticisms I should like, however, to say that we have not reached anything like finality, and that we ought to, and we do, welcome every attempt that is made, or every suggestion that is brought before us, with a view of improving the telephone service of the country. The problem which is ever present to the mind of the telephone engineer is simply this—to place the subscribers in communication in the shortest possible interval of time, with a due regard to a reasonable capital expenditure, and by the employment of the fewest possible number of operators. This problem has been ever before them, but as new devices have been introduced which appeared to simplify the problem the difficulties have increased, owing to the growth of the population and the growth of telephone subscribers. As the last speaker said, it is only a few years ago when the multiple board was supposed to meet the requirements of a given locality with a capacity of 6,000. Now a multiple board of 15,000 is actually in existence. A 20,000 board is designed, and that is still far from meeting the requirements of the public; and if anything in the nature of Mr. Aitken's proposal—which certainly is an honest endeavour to meet the difficulty—can be adopted, then I say he is conferring a benefit on the community in bringing the subject forward. The divided multiple boards that have been used in America can hardly be said to bear very seriously on the problem, because they do not provide automatic signalling—at least those that I saw did not. They are all the old type, involving ringing up and ringing off, and whatever may be said for or against them there is very little in common between them and those proposed by Mr. Aitken. Mr. Aitken's statistics are not universally applicable; some of them have been referred to by other speakers. With reference to others, I should like to point out one or two matters, not in a carping spirit, but merely with a view of preventing any misunderstanding. The author has made certain definite statements as to the number of subscribers per operator, the work carried by junctions, the time in getting through, etc., etc. I should like to point out that you cannot determine these factors directly without first of all postulating the number of talks per subscriber and the type of apparatus that you are using. In the first place, with reference to the apparatus, I do not think you can make any definite comparison between the old type of ringing on and ringing off and the modern type of automatic signalling. I have a very firm conviction that the introduction of automatic signalling, in which you merely remove the telephone to call and place it back to clear, in which the signalling on the junctions is wholly automatic, in which the talking is reduced to a minimum, the operator simply being called upon to ask for the number—and by the signalling she sees perfectly well what is going on without intervention—I cannot help thinking that with a system of that sort, a system which I think before many years we shall see universally employed, the capacity of an operator and the carrying power of the lines will be absolutely doubled. I

Mr. Gavey.

Mr. Gavey. must confess that I have some sympathy with certain of the speakers on the question of reducing the work of the public to a minimum. At present, with the automatic system, that is absolutely minimised. Tell it not in Gath, but I also am a telephone user, as well as being connected with the engineering branch of the Post Office telephones. I happen to have on my table a little switch with three keys. I am frequently called to the telephone when immersed in business, immersed in thought. I think at such a time that the telephone is a nuisance, but I have to answer it. I answer it as quickly as possible; I put it down and go on with my work, and presently somebody rushes in hurriedly and replaces the key, which I myself have forgotten to do. I hope I am not an unintelligent user of the telephone, but I mention that as one of the difficulties you have to contend with, apart altogether from want of ability or want of care. When a very busy man who is immersed in business, whose mind is full of very important matters, is interrupted he just does what he has to do, and no more, forgetting the little details that are involved in the special work of clearing off.

Mr. Aitken. Mr. W. AITKEN, in reply, said: Mr. Webb made considerable reference to the cost of the outside plant, but it is to be noted that in my schedule of quantities I have shown how an increase of 550 yards on each of the second 15,000 lines is obtained by the reduction in the number of junction lines. It is also to be remembered that the great mass of wires centralised on one great exchange will be cheaper per mile owing to larger capacity cables being used and the decreased cost of labour in laying. Mr. Dommerque, of the Kellogg Switchboard and Supply Company of Chicago, takes a great interest in this subject, and I would take the liberty of quoting some information given in correspondence I have had with him. In a report made by him some years ago, which is still valid as regards arguments but out of date as regards prices of materials, he says: "As the cost of the installation of the wire plant is not the item that is involved in the cost of telephone service, but the annual expense, the interest and depreciation, maintenance and taxes on the wire plant is the factor that must be taken into consideration when comparing the preference of one system over the other." From this he goes on to compare the two systems, allowing 0·35 miles of wires per subscriber for the junction system, and 2·6 wire miles on the divided system when dealing with one 10,000 line exchange against four 2,500 line ones connected by junctions, and yet shows a result in favour of the divided system. He concludes as follows: "It may be of interest to note some points in which the single-office system excels the multiple system outside of the monetary question. Necessarily the condensation of all apparatus into one unit allows of the best supervision and regulation of the system."

"More than anything else weighs the circumstance that each call in the one-office system is handled by one operator only, which not only allows of the highest speed in obtaining connection but also ensures less mistakes than when calls are handled by two operators as it is the case with the 60 per cent. or more calls that are trunked between the four or more offices of a multiple-office system. Even with the best trunking facilities it happens that in the multiple-office system during

the busiest hours just when the trunks are most useful the service breaks down." Mr. Aitken.

"Trunking requires more office cable and more contacts in the talking circuit, and thereby deteriorates the transmission of speech. The efficiency of apparatus like ringing machines, storage batteries and their charging machines, is greater with one-office system, because larger units are always more efficient and easier to maintain than smaller units, certainly when the latter are scattered over several places."

Mr. Dommerque in his letter adds: "I wish, however, to state that with the introduction of $\frac{3}{16}$-inch and even $\frac{1}{4}$-inch jacks, large switchboards can be built without going to division-systems. In fact, we would be able to build single division-boards for 25,000 subscribers. This, of course, will also increase the range of division exchanges, because, with these small jacks, we will be able to build division boards up to 50,000 lines, using only two divisions, and correspondingly greater, by using more than two divisions. The whole matter will sum up in the advisability of having only one exchange in a city, against several exchanges."

With reference to the other points raised by Mr. Webb, particularly that regarding the operating by the subscriber and which nearly all succeeding speakers have also remarked on, I think too much is being made of this, and that Mr. Webb is prepared to pay too much for uniformity. Get a subscriber to understand that by performing a certain act he will receive quicker attention with fewer possible mistakes, and I am sure he will do it. He wants a quick and reliable service, and is prepared to do anything reasonable to obtain it. Automatic clearing is essential on such a system as I advocate, but automatic calling is not essential on any system, in fact it may be looked on as a doubtful facility. The absent-minded man may unconsciously allow the lever of his desk telephone to rise and indicate a call, or the charwoman or servant when cleaning remove the receiver to more conveniently perform her duties, thereby giving the operator unnecessary work and trouble.

It is to be borne in mind also that business men use press buttons—and more of them, and often code-riming on each—in connection with bells to call clerks, and when a mistake is made the man usually recognises that he has wasted his own time and that of his clerk unnecessarily and is more likely to be apologetic than use Mr. Webb's phrases.

The buttons might be coloured as mentioned by Mr. Kingsbury, red, white, and blue, and all numbers in the book would be preceded by one or other of these words, so that there would be no excuse for mistakes. Why does a subscriber on the present system not ask for Avenue when he wants Gerrard? One is almost as likely a thing to do as the other.

Mr. Webb thinks my values of calls too high—probably they are if you consider only calls from one exchange to another, but what about those that pass through one or two intermediate exchanges, which take much longer? The average is not very far out. I should like further particulars of Mr. Webb's figures—figures have a bad reputa-

Mr. Aitken. tion. The following will give an idea of the work required for the two calls :—

LOCAL.

(1) Inserts plug in jack over lamp glowing.
(2) Pulls over listening-key and takes requirements from subscriber.
(3) Tests line wanted, and if free inserts plug.
(4) Puts key in through position.
(5) When cleaning lamps glow withdraws two plugs.

JUNCTION.

(1) Inserts plug in jack over lamp glowing.
(2) Pulls over listening-keys and takes requirement from subcriber.
(3) Presses call-key and repeats number wanted to distant operator (may have to wait her turn or repeat number more than once).
(4) Junction operator allots line, tests line wanted, and if free inserts plug in jack.
(5) Presses ringing-key.
(6) First operator inserts plug in junction jack.
(7) Pulls key to "through."
(8) When cleaning lamps glow withdraws two plugs.
(9) Junction operator withdraws plug.

I find it difficult to understand Mr. Webb's reference to private branch exchanges relieving the great centrals to any appreciable extent. Very few firms in this country at least would care to pay for an exchange line when a local private line would serve the same purpose. There is certainly room for developing the private branch exchange business.

With reference to Mr. Gill's remarks, for obvious reasons I could not very well deal with a definite problem; I should certainly have preferred doing so, and have no doubt I could have shown even better results. To the telephone engineer who would consider the points put forward by Mr. Gill, I would say, Do not overlook the other points put forward in favour of the divided system. As before mentioned, the maintenance costs require careful attention and will be found to well outweigh the capital costs. Mr. Gill's alarming figures of excess weight of copper in my system are based on a hypothetical case, and I believe have no sure foundation—at least are not sufficient to outweigh the other advantages.

With regard to the percentage of junction calls, I think most subscribers would be content to wait twice as long for a few calls to their houses in the suburbs if they were assured of getting the great majority of their business calls in the shortest possible time. If Mr. Gill deducted the small exchanges from his figures the results would be very different.

Mr. Harrison's alternative system, judging by the meagre descrip-

tion given, is in my opinion practically unworkable. I believe he means to put two subscriber's lines on one springjack by using springs of different lengths and a split bush or test ring. On a 10,000 line exchange an operator could not test with certainty. When a call was received for the B subscriber when a connection had already been made by the same operator to the A subscriber, how would it be done? Would not the jack need to be enlarged to get in the six connections and the necessary cable? Mr. Aitken.

I have some difficulty in understanding Mr. Kingsbury's opening remarks. I have not read my paper to provoke discussion, but to describe a system I believe capable of providing an efficient telephone system for the world's capitals. The system is beyond the experimental stage in at least the two divisions—in that there is nothing untried, and only in one of the great cities can the experiment (if experiment it can be called) of introducing it be efficiently tried—and when some engineer or corporation with sufficient courage does adopt it I have no fear of the result.

Mr. Kingsbury refers to Mr. Poole's system used at Manchester some years ago. The idea was excellent—the push-button arrangement had, I understand, nothing to do with the partial non-success of the system, but the weakness lay in the polarised ring-off indicator.

Mr. Kingsbury's four-area system is altogether too vague to allow of its being considered here.

When writing my paper I overlooked a patent taken out by Mr. Kingsbury's Company on June 1, 1900, for divided boards on a somewhat similar system to mine, but instead of using two push-buttons, two instruments were to be connected to the line at the subscriber's office. This is open to all the objections of the push-button.

I have to thank Mr. Gavey for his kindly remarks. I agree with him as to the object to be aimed at in designing a telephone system. There is no doubt the ideal system should have all subscribers in the same telephone area in one exchange. In the world's capitals this, with our present knowledge, is not possible, but the nearest approach to it should certainly be made. To the various features necessary for quick and reliable operating mentioned by Mr. Gavey I would add the reduction to the minimum of junction working with complicated circuits and the necessity for the repeating of numbers by operations.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Members.

Harry Collings Bishop.	Edmund Munroe Sawtelle.

Associate Members.

John Arnot Anderson.	Edward Peter Grimsdick.
Albert Arthur Blackburn.	Harold Aislabie Howie.
Charles William Dawson.	William Arthur Molyneux.
John William Dawson.	Sidney Cuthbert Sheppard.
Axel Carl Ludwig Ekström.	Arthur Denby Smith.
Rudolph Goldschmidt.	James Herbert Targett.

Associates.

Leopold Charles Benton.
George Henry Broom.
William P. Dunne.
Arthur Herbert Flemming.
Algernon Coste Gilling.
Percy James Haler, B.Sc.
William H. W. James.
Harold Morton Middleton.
William Carmichael Peebles.
Alexander Russell Walker.

Students.

Algernon Edward Berriman.
Geo. Bradwell.
Ernest Phillip Elwin.
Herbert Geo. Jenkins.
Alfred Montgomery.
Stanley Robert Mullard.
Patrick F. Myers.
James Parkinson.
Alfred William Scrooby.
Arthur Douglas Taberner.
John Dodsworth Walker.
Arthur Ward.

GLASGOW LOCAL SECTION.

DISCUSSION* ON ELECTRIC WIRING UP TO DATE.

(*At Meeting held January 13th,* 1903.)

At a discussion on the above question which was opened by Mr. Chamen, attention was drawn to the number of outbreaks of fire which had occurred owing to bad wiring, which were attributed to the use of metal sheathed tubing with slip joints.

The opinion was expressed by Mr. Chamen and subsequent speakers, that this class of protection for wiring had not answered anticipations, and in fact it was doubtful whether it was as safe as wood casing.

Where iron tubing was used it was proposed that it should be made with screwed joints throughout and earthed.

* For a fuller account, see *The Electrical Review*, vol. lii., p. 329 ; *The Electrician*, vol. l., p. 1071.

NEWCASTLE LOCAL SECTION.

METHODS OF SUPPORTING AND PROTECTING INSIDE CONDUCTORS.

By O. L. FALCONAR, Associate Member.

(*Paper read at Meeting of Section, January* 19, 1903.)

Introductory.—In order to meet with the exigencies of the gradually increasing pressure of supply, and also to cope with the demand for more reliable and less expensive methods than those at present used, it is imperative for electrical engineers constantly to recur to a subject which has ultimately a most important bearing on the success of any electrical undertaking. In view of the general tendency towards standardisation in electrical apparatus which has been a prominent feature of the last decade, it is remarkable that "methods of supporting and protecting conductors" should remain in such an undecided state. Possibly this may be in some measure owing to the small amount of attention the general body of electrical engineers have given this subject, and to their confining their efforts more towards reducing the cost of production and distribution of electricity. That an improvement in the present methods is necessary is clearly shown by the excessive amount of labour required to carry them out; moreover, the cost of wiring appears to be increasing rather than diminishing, and this, in the face of recent vast improvements in gas-lighting, threatens, unless remedied, seriously to curtail the advancement of the use of electricity. As far as the author is aware, previous papers bearing on this subject have chiefly been confined to the discussion of some particular system advocated by or associated with the writers; hence the subject has not perhaps been considered in as broad a light as from the standpoint of a person who has in most instances to decide what method he will adopt, and is also held responsible, both morally and pecuniarily, for the good working of the undertaking. The author hopes on this occasion to consider as many as possible of the present systems in use, with the object of deciding which is the most efficient and economical method to be used for the various conditions required, and in order that this may be done he trusts that any member who may be familiar with systems not treated on in this paper will at the close take part in the discussion. As the conditions under which the conductors will be required to work ought to determine which system is requisite, it should be possible to divide them into various groups and to standardise to as large an extent as possible the method to be adopted for each case. The author has, therefore, endeavoured broadly to classify the conditions usually met with under the following headings:—

(A) *Exposed Positions.*—This may be considered to apply to the

wiring of very rough places—for instance, certain parts of shipyards, boiler shops, forges, collieries, etc., where damage to the conductors from mechanical injury, dampness, corrosive salts, gases, or other causes have to be provided against.

(B) *Ordinary Positions.*—Or places where damage from outward mechanical injury to any great extent is not to be apprehended, but protection against general dampness, vapours, corrosive salts in plaster, etc., must be allowed for. Instances of this class occur in all new buildings, mills, warehouses, and workshops.

(C) *Unexposed Positions.*—Or places where no deleterious effects other than the actions of the atmosphere, and general deterioration owing to ordinary wear and tear are to be encountered. Such conditions are met with in certain offices, shops, dry goods manufactories, etc.

The author does not wish it to be supposed that he considers the above classes should be made to embrace the whole of the conditions met with in practice, but in order to avoid the introduction of a subject which in the limited time at his disposal would be impossible to discuss fully, he has taken them as a basis on which to work.

CLASS A.—EXPOSED POSITIONS.

The requirements, then, in regard to the methods of supporting and protecting conductors for Class A may be briefly stated as follows :—The conductors must be rigidly supported throughout their entire length and protected by a substance which will withstand continual rough usage ; they should, moreover, be protected from moisture and be capable of being added to or withdrawn without undue inconvenience. It is obvious that such substances as wood casing, insulating cleats, or any form of split tubing would be unsuitable for this class, and one of the commonest methods is to draw the wires into "iron gas-barrel."

Iron Gas-Barrel.

This, no doubt, has been, and is, in many instances, used with success, but there are many objections to this system. Lack of flexibility, interior roughness, extreme difficulty in preventing damage to wires in drawing in, and rapid deterioration of cables owing to internal moisture, are some of the principal ones. As the question of cost of each system will be considered later, this may at the present moment be ignored.

The difficulties which arise, especially where tubing of large diameter has to be used, in getting round irregular-shaped bodies with any pretence of neatness, will be appreciated by any one who has had experience in the wiring of motors used for driving large power machines in this class of conditions. Standard bends, elbows, and tees can in many instances be used, but where special bends are required for these purposes they waste an enormous amount of time and patience.

Interior Roughness.

The ordinary class of gas- or steam-tubing is, moreover, unsuitable for use as a protection to any but armoured cables owing to the interior roughness which invariably exists. This cuts through the covering of the cables when they are drawn through, and in time causes an endless amount of trouble. Tubing should only be used after having an iron rod of nearly the same diameter as the inside of the pipe driven through, and the ends should also be rimered to remove any sharp edges after this is done. It is important that insulating bushes of hardwood or other suitable substance should be fitted at the point of entry or exit of cables from any kind of metallic piping, and the author has records of numerous breakdowns of wiring owing to neglect in attending to this very simple precaution.

Screwing.

The screwing of this class of tubing, besides taking a large amount of time, is another source of danger to cables. The oil used for lubricating the die, unless carefully wiped off the tube, is very apt to get on to the cables, and plays havoc with any type of rubber coverings. The sharp edges left on the ends of the tubes after screwing are also likely to be overlooked and to puncture the insulation of cables. Though it may be thought these objections arise only where careless workmen are employed, yet they must always be guarded against, and with the class of workmen usually procurable extreme care is more than can be expected. Packing cables owing to the use of too small diameter of tubing is a great cause of damage. The author has found that tubing of less than $\frac{3}{4}$ in. inside diameter is little use in the case of a draw-in system where looping is substituted for jointing.

Jointing.

In jointing this class of tubing a watertight joint is not obtained so easily as is apparently supposed by many—viz., by running a few threads into a coupling without any form of packing. In moist places, no doubt, rust will in time help to fill up any crevice; but where cables are led amongst machinery and in places where oil is likely to be scattered about, great care has to be exercised to avoid this finding its way through loose couplings. If red lead is used, it should be kept well off the end of the tube to which the coupling is screwed. Tarred spun yarn or asbestos twine appears to be suitable for making water-tight joints, but the author is not aware if they would resist oil. Possibly lead wire would be suitable for this purpose.

Internal Moisture.

The deterioration of cables through internal moisture produced by condensation is a defect common to all metallic tubing methods, and often causes serious faults to develop after the installation has

been working for some months. Whilst much of the moisture attributed to this cause finds its way from the outside through imperfect joints, in numerous instances which come under the author's notice this has undoubtedly been the cause of trouble. In long vertical runs, terminating at a switch or fitting, water often collects, and develops an earth or short-circuit. In horizontal runs it collects at bends or dips in the pipes, and the cables often break down at these points. There are three methods of overcoming this: (1) drainage holes or traps may be adopted, and the pipe given a slight fall to these positions; (2) the wires may be lead-covered or enclosed in some other suitable watertight covering; or (3) the tubing may be coated with a non-conducting substance such as paper, which is said to prevent the formation of moisture by condensation, this tubing being generally of welded steel of thinner gauge than ordinary gas-barrel. (*Note.*—The author has not heard of ordinary gas-barrel being coated with an insulating substance, but possibly this may be procurable.) The author believes the second method is to be preferred, as it is impossible to prevent moisture collecting in some parts of the tubing, in spite of drainage boxes or vents; and the third method, besides providing a porous substance which may, if water finds its way into the tube, remain damp for a longer period than an unprotected pipe, destroys one of the greatest advantages of iron pipe work—viz., the prevention of unnoticed leakage by immediate dead earthing, and consequent warning by the blowing of the fuse protecting that circuit.

Welded Steel Tubing.

Heavy-gauge, uninsulated, welded steel tubing of smooth interior can be obtained at a slightly higher cost than ordinary gas-barrel, and this overcomes the difficulties due to roughness. Other disadvantages arise, however. The thickness of the tubing is hardly enough to allow of a "Whitworth" full standard thread being cut, so the makers supply special dies cutting a much finer non-standard thread, which is a great inconvenience to users, especially as each maker recommends a different type of thread which he has found, after careful experiment, to be exactly suitable for the purpose. This seems like retrogression, and reminds one of the old days, when each engine builder manufactured his bolts and nuts with a special thread, so that future repairs would have to come his way. It seems unfortunate, also, that more uniformity does not exist in regard to the diameter of this class of tubing. Some makers apparently take the inside measurements, others the outside; some take the diameter in millimetres, others in fractions of an inch; whilst some disregard both, and arrange their tubing alphabetically, such as A size, B size, or C size. It is unnecessary to enumerate the benefits which would result if uniform dimensions were adopted by every maker, but possibly the makers themselves realise that any form of heavy screwed piping at its best is a superfluous and expensive method to adopt, and expect it to be superseded sooner or later by some simpler and more easily fixed system. One method which suggests itself to the author as a substi-

tute for iron piping in this class is the use of "armoured cables." In the author's opinion the protective substance should form part of the cable itself, and if this were of sufficient strength, the cables might be clipped on to the surroundings in the same manner as in an ordinary gas installation. There is, of course, nothing new in this proposal. The advocates of concentric wiring have endeavoured to introduce a system similar to this for years, but judging from the small amount of this class of work done at present (inside buildings), it is apparently not desirable to alter the present system of double wiring. There is no reason, however, why two armoured conductors should not be run in buildings of this class in the same manner as is done in most ship installations. In ship wiring this method has been used for some time with considerable success in positions in this class, and also in classes B and C.

CLASS B.—ORDINARY POSITIONS.

In Class B, though the risk from damage by mechanical injury may not be so great, the dangers due to the other causes referred to—viz., general dampness, moist vapours, corrosive salts in plaster, etc.—often cause much trouble in practice. It is often desirable in this class that the conductors be enclosed in plaster or concrete, containing a considerable amount of moisture and often corrosive salts. In such cases, the author has found any kind of split tubing without watertight joints very unsatisfactory, and faults often occur after installations of this nature have been completed and running for a few weeks. Of the present methods in use, the welded steel tubing already referred to, with screwed unions, appears to give the best results, and the cables should be drawn in *after the tubing has been fixed complete,* and the surroundings have become as dry as possible. Draw-in or inspection boxes have, of course, to be fitted in this case, and much inconvenience will be avoided in the future if these are left easily accessible so that cables can be withdrawn if desired. If let into plaster work, their lids should come flush with the outside layer, and should have some distinctive marking, or if under floors, a trap should be left to allow of easy access, and at the same time to mark their position.

BRAZED STEEL TUBING.

Steel brazed joint tubing has not been found satisfactory by the author. The brazing is often badly done, and splits at the least provocation. In this class of tubing, as with iron gas-piping, great care must be exercised in removing all burrs or sharp edges after cutting and screwing, also in insulating pipe ends and allowing ample room for conductors. The author has found in some instances that cables which were drawn into tubes with little difficulty required a considerable effort to withdraw them after a few years' time owing to the inside of the tube becoming rusted. If all elbows or sharp bends are strictly prohibited, however, the difficulty in drawing in or out is considerably reduced, but if unavoidable, they should be of the inspection type,

Wood Casing.

Wood casing, if well coated with shellac varnish, or other waterproof composition, may also be used in this class with success, but *non-waterproof casing should never be used,* owing to the objections already referred to in the case of insulated metallic tubing; and with wood casing, owing to its inflammable nature and there being no metallic sheath, these objections have much greater significance. Since the increase of pressure in the Newcastle district the author has heard of numerous instances of slight fires occurring through the use of unprotected casing in this class, aud one which came under his notice, and was, curiously enough, in a fire insurance company's office, demonstrates clearly that even a well-designed installation is not perfectly protected from a fire occurring from this cause. In the case referred to a leakage to earth of not more than one or two amperes at 240 volts was sufficient to make about 3 in. or 4 in. of 1½ in. diameter casing incandescent, and had any inflammable material been near at hand the result would probably have been a serious fire. This circuit was protected by a fusible cut-out on each pole. The fuse wire consisted of No. 22 gauge lead wire.

Non-Metallic Tubing.

The use of non-metallic tubing for inside conductors has, rather strangely, not made any great headway during the last few years. In the case of new buildings, earthenware tubes or ducts let into walls during erection would, the author thinks, make an excellent system of protection if this could be carried out to satisfy the requirements of a modern householder. This he is afraid, however, would not be easy to do, as the exact positions and arrangement of lights would obviously have to be fixed before the building is up. It would also be a difficult matter to fix additional lights after such an installation is completed, and the cost is probably much greater than that of metallic tubing. For factories and warehouses, however, these objections may not apply to such an extent, and the author would be glad to hear if any member has tried such a system.

Bitumenised Fibre Tubing.

A few years ago this was said to be the coming thing. Among the numerous advantages ascribed to it was that it was "impervious to moisture," "fireproof," and "rat-proof." The first and second are certainly not precisely accurate, as the author has on several occasions come across pieces of this class of tubing which have become quite "pulpy" after being a few years in a damp position, and it is fairly easy to ignite a piece of this tubing at a fire. It is evident, however, that for a short time this tubing will resist moisture, and it is also doubtful if any heat likely to arise from electrical causes would make it take fire, so in many respects this tubing shows distinct advantages over wood casing. The author has not tested the "rat-proof" qualities of this tubing, but is quite prepared to admit of its being offensive to the

digestive organs of this type of rodent. The greatest objection to bitumenised fibre tubing is its brittleness. A slight blow with a hammer, given accidentally when fixing, splinters it, and it cannot be bent to any appreciable extent. The method of jointing by means of thin brass sleeves is also defective, and tee-pieces and draw-in boxes seem unknown. It has already been noted that it is desirable and often imperative for the cables to be surrounded by a conductive sheath, so it is doubtful if any systems which do not fulfil this condition will ever be universally adopted, unless the insulating properties of the supporting or protective medium can be so absolutely relied upon that the use of insulated conductors is unnecessary.

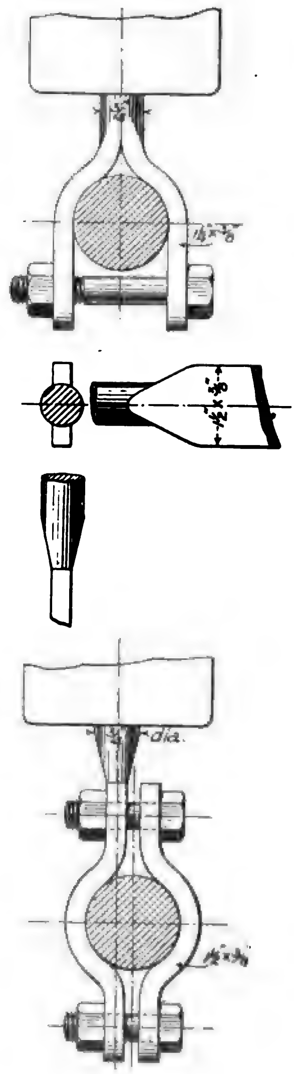


FIG. 1.

INSULATORS.

The foregoing remarks bring before our notice the use of insulators. These form an excellent method of supporting cables, and give protection from leakage due to moisture, but, of course, form no mechanical protection. In many cases, especially in workshop wiring, cables can be carried (except where led to or from distributing boards, motors, or lights) at such a height from the ground that all possibility of damage from this cause is avoided. Insulators in these instances are eminently suitable, and by reducing the cost of erection greatly enhance the "break-up" value of the installations. The various forms of insulators used and methods of fixing are so well known, that comment is unnecessary. A word may be said, however, in regard to the securing of heavy cables of 0·4 in. diameter or larger. These should be laid on a suitable grooved insulator, fixed so that the weight of the cable is carried directly by the insulator and not by fastenings, which are likely in time to wear or get eaten through and break. Exception to this, however, may be taken in regard to underground colliery workings, where it is sometimes advisable to have the cables secured in a comparatively flimsy manner to avoid them being broken or damaged by

falls from the roof. Porcelain buttons or cleat insulators in two halves, which grip the cable when screwed up, are very useful for small wires, and seem likely to come into use to a large extent in the future. A common fault in most of the cleat form of insulators is the exceedingly small screw holes allowed; this, however, is a matter which can easily be rectified by the makers. In large iron buildings without any woodwork, such as shipyard sheds, etc., not a little ingenuity has sometimes to be displayed in the fixing of insulators to the surrounding iron work. In an installation recently carried out by the author's firm at a large engineering works on the Tyne the mains were carried across the tie-bars out of the way of the travelling cranes by means of ordinary double-shed insulators fitted with special clamps instead of bolts (Fig. 1). These are very easily fixed, and make a sound mechanical job. All kinds of varieties of these clamp insulators can be obtained. Wooden battens bolted to girders or columns, or iron brackets, such as shown on Fig. 2, may be used for securing the smaller wires when button insulators are used. There is another advantage to be derived from the use of insulators—viz., the wires can be traced by the eye and faults generally seen. Moreover, when discovered, they can be easily rectified without having to withdraw the wires from tubes or to cut open walls or floorings, etc. Although, at present, insulators are used only for workshops or plain buildings, the author sees no reason why a modified form should not be used for better-class buildings and private houses. On the Continent the author understands a large amount of lighting wiring has been carried out by means of twin flexible wires supported by insulated clips. This method would certainly reduce the cost of the wiring considerably, and if twin conductors heavily insulated were used instead of the ordinary thinly-insulated flexible, this system should be perfectly sound.

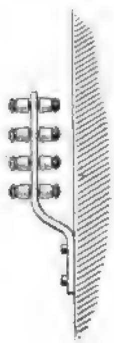


FIG. 2.

CLASS C.– UNEXPOSED POSITIONS.

Our old friend wood casing, which has been in existence since the earliest days of the commercial application of electricity, has on several occasions been condemned as obsolete by eminent authorities. In spite of this, however, it still exists, and, personally, the author regards this method as being equal to many at present used for this class. While the objections referred to in Class B condemn it in any but perfectly dry places, in old buildings, especially large houses and offices where it would be inconvenient and difficult to place the wiring out of sight, casing is still an easy method of enclosing conductors, and makes a neat-looking job.

SPLIT TUBING.

Light gauge tubing of the "Simplex" class, with what is termed "close" joint, but which the author would prefer to call "split tubing,"

as the term "close" joint is certainly inclined to be misleading, is also used in this class, and is regarded by some as a more mechanical system of wiring. The tubing being jointed by being simply pressed into tapered couplings, enables it to be fixed at about half the cost of screwed joint systems. This class of tubing, however, requires rigid support, as it is very much inclined to work loose, especially at bends and tees, and this gives the job a very shoddy appearance. Saddles should always be used in preference to pipe hooks for this purpose. On the whole, the author does not think this system has much to recommend it, except, perhaps, that it can be fixed by less highly-paid men than can wood casing.

Lead-Covered Wiring.

Lead-covered cables clipped direct to surroundings by brass saddles is, in the author's opinion, a much better method than either of those referred to, and combines the advantages of simplicity, reduced cost of erection, immunity from moisture, and easy localisation of faults. From an æsthetic point of view this may be objected to, but if the wiring is carefully carried out and runs kept perfectly straight without sagging, the appearance is as good as wood casing or tubing on the surface. Some excellent work of this class has been done in ship-lighting, and probably the reason why this method has not been more generally adopted for buildings is to be found in the conservatism of fire office officials, and, one might also add in some instances, supply companies' regulations.

Flexibles.

The protection of flexible conductors in unexposed places, is, perhaps, more a question for cable manufacturers, as it largely depends on the materials used for covering them. In exposed places, however, this matter sometimes needs special attention. It is desirable in such cases to limit the amount of flexible used as much as possible, and the vast improvements, or, perhaps, one might call it enlightenment of the electrical fittings' manufacturers during the past two or three years, has led to this being practicable with any fittings likely to be used in this class. Portable lamps, however, are often required, and these being probably subjected to more rough treatment than any other part of the installation, faults frequently occur in the flexibles attached to them. After experimenting with various kinds of armoured flexibles for shipyard use, the author found that the ordinary workshop class enclosed in flexible bronze or steel gas-tubing gave the most satisfactory results, and, with the exception of being somewhat costly, this method appears to be suitable in most instances where extremely rough conditions are experienced. In ordinary cases armouring composed of galvanised steel wires or steel braiding is sufficient to protect the flexibles from being cut or damaged by rubbing against rough bodies, but as oil has a very rapidly destructive effect on them, the tubing method will be found much more reliable if there is any chance of the cables coming in contact with the substance.

Question of Cost.

In ascertaining which is the most suitable method to be adopted in each class, the question of cost demands careful attention. Reference has already been made to the excessive cost of erection; in some instances this very nearly equals the value of the materials used. An analysis of the cost of the various methods referred to in this paper would, therefore, be interesting, but in endeavouring to obtain this from actual instances, the author found it impossible to make anything but a very approximate comparison owing to the great variations in the conditions of the different cases. The figures, therefore, of the accompanying table must be taken only as representing the average cost per point for erection, support, and protection of conductors in installations which have come under the notice of the author during the past three years.

Approximate Cost per Point Single Light Wiring Inside Buildings.

Method and Class.		Materials.		Labour.		Total.	
		s.	d.	s.	d.	s.	d.
Iron gas-barrel	A	13	0	12	6	25	6
Screwed welded tubing	A	13	6	10	0	23	6
Armoured cables	A	9	0	8	0	17	0
Insulators	B	6	5	5	2	11	7
Painted wood casing	B	7	6	6	0	13	6
Ordinary wood casing	C	6	7	6	0	12	7
Split steel tubing	C	7	0	6	0	13	0
Lead-covered wires (clipped direct)	C	5	9	4	6	10	3
Insulators (cleat type)	C	5	6	3	9	9	3

It will be noticed there is a considerable difference in the cost of erection between screwed and unscrewed tubing, the latter costing about half as much to erect as the former. Whilst this is owing partly to the amount of time taken in cutting and screwing the heavy-gauge piping, it must not be overlooked that very unfavourable conditions of working generally exist where this class of tubing is used. When armoured cables have been used by the author, however, the conditions have been similar to those in which screwed tubing has been used. Thus it will be seen that a very considerable saving is effected in the cost of an installation of this nature. In Class B the additional labour required for screwed tubing compared with wood casing or insulators is still noticeable. In Class C the cost of cleat insulators and lead-covered wires clipped direct come very near to each other, and both are easily removed if required. Conditions vary so greatly in regard to the surroundings of electrical installations that the author feels it would be imprudent for him to define any system as alone being suitable for any of the classes referred to. Generally

speaking, however, he is of this opinion: That for Class A some form of armoured cables will in the near future be adopted as a standard for this class. For Class B he is of the opinion that for surface work, waterproof painted casing, and for covered wiring behind plaster work, screwed welded tubing are the most satisfactory methods. For Class C either cleat insulators or lead-covered cables, according to circumstances. Insulators other than this type may be taken almost as a separate class and form, as already mentioned, a highly efficient method in the class of buildings suitable for their use.

In the event of dismantling and taking down of conductors, insulators undoubtedly stand as the method which gives greatest facilities and highest value for old material, and this is sometimes a matter of importance in carrying out an installation which is to any extent of an experimental nature. Wood casing, though not as expensive to erect as screwed tubing, is practically of no use after being taken down, and it costs more to dismantle than the value of material recovered. Owing to the few instances he could refer to, the author was unable to obtain any reliable data in regard to the cost of taking down cables fitted in accordance with the methods referred to, but it is obvious that with piping the conductors would be more likely to be damaged or cut into short lengths than with armoured cables, and consequently to be of less value as old material.

The author hopes these somewhat brief and incomplete descriptions given by him of a few of the methods in general use will have been of some interest, and he trusts that this paper may open the way to a full discussion of the subject which will tend towards greater uniformity in methods in supporting and protecting inside conductors.

Mr. J. H. HOLMES (*Chairman*) said that the paper was one which lent itself to a good discussion. As Mr. Falconar had mentioned his name as having sent a board of samples, he would like to tell the members how the tubing to which the author of the paper referred was made, he having seen it manufactured both in America and Germany. In the former country the interior conduit system was largely used. The tubing was made out of long strips of paper rolled round and round, one in one direction and another in another, until the requisite thickness was obtained. The tubes were cut up and dipped end-ways into an asphaltic composition. It was quite hot when dipped, and it dried and formed very solid. He did not think tubing got pulpy when made in this way. In America they found the tubing liable to damage mechanically by people putting nails through it, and they therefore provided it with a steel covering. Mr. Holmes

The American system differed from that of Germany, for in that country Mr. Bergman made it on quite a different plan. He made the tubing out of very good quality thin sheet steel, which, after bending, was brazed. The steel tube was made a little larger than the asphaltic tube, which was placed inside. The steel tube was then actually drawn down on to the asphaltic tube (which was somewhat longer than the steel tube), during which process the steel tube got smaller in diameter and greater in length until the asphaltic composition made a very firm lining.

Mr. Holmes. The unions were also a very fine piece of work, and were actually cold-pressed out of sheet steel. The brass-covered tubing was similarly made. Bends at any angle were easily obtained by the use of a tool. He noticed Mr. Falconar suggested the use of lead wire for making joints in the tubing, but he did not quite see how this could be used.

Mr. Woodhouse. Mr. W. B. Woodhouse said that his experience of split tubes had forced him to the conclusion that such tubing should not be used where there was any moisture; L-pieces should never be used. He found a cheap construction was gas-barrel, screwed into cast-iron junction-boxes, which, if properly supervised, could be made watertight; much of the trouble with internal burrs arose from using pipes too small for the purpose. Wherever possible he preferred to use clip insulators; for small wires the button insulators were excellent, but the weak points of such wiring seemed to be at the switches and ceiling roses, for with the fittings now on the market it was necessary to mount these on wood. He suggested that these fittings should be arranged like the clip insulators, so that a rose might be fixed straight on to iron work and yet have the wires surrounded by porcelain. With reference to the double-shed insulators, the speaker disagreed with such construction, because it needed binding wire, which he considered an abomination. He sketched a type of insulator made by the British Thomson-Houston Company, which could be mounted singly or in rows in a very cheap and effective manner: it was suitable for all cables larger than 7-18s, and although the cable was firmly gripped by the insulator it was easily removed. With reference to the use of flexible metallic tubing for protecting hand-lamp leads, his experience had been that such tubing was not oil-tight, and on account of its strong appearance got very rough treatment, which caused it to break and cut into the lead. He preferred to use ordinary workshop flexible, with a heavy outer coating of jute and a protecting iron wire; this was fairly strong, would stand a considerable amount of oil, and was cheap to replace. In places where much oil was to be met with, lead-covered wires were the only wires that could be used, but the oil always got to the end of the lead, at the switch or lamp fittings, and he met the trouble by sealing in the conductors in a porcelain or metal box, just as in a cable dividing box.

Mr. Newitt. Mr. L. Newitt said he had very little to do with contract wiring himself, but, at the same time, was anxious to know what others had done. On reading over the paper he had not discovered that any one of the systems described was perfect. For example, if we took any one of the systems requiring steel tubing, we put ourselves very much in the hands of the plumber or engineer, who had to screw and fit up these pipes, and it was often found that a sharp rag was left on the piping, which tore the insulation off the wires; or the pipes were not watertight. Also, if piping were used, we had to consider the increased cost of the installation which, when work was undertaken at about 12s. per light, would not leave sufficient margin for doing really good work with piping. It had also been noticed that in some cases condensation in the pipes occurred, and then it was only a question of time before the installation broke down.

With regard to the remarks on rat-proof cable, he had heard it said that rats never bit tubing unless they heard water running inside of it; so that they need have no fear on that score. Mr. Newitt.

With reference to the tubing which was insulated on the inside, it was almost impossible to retain the insulation intact around bends and joints where it was particularly required, and in fact any piping that could be used did not appear to be entirely satisfactory.

As regards wood casing, he (Mr. Newitt) quite agreed with the writer of the paper that, except in isolated cases, it was not to be recommended. Personally, he thought that the more wires were exposed the less likely they were to cause trouble, provided that at points where they were liable to external injury they were protected by a suitable guard. To illustrate how a system of wiring without casing or tubing could be carried out, he had brought with him a complete model of a section of wiring, showing how a friend of his had fitted up his building, and he trusted that some of the members would give their opinion on the arrangement.

As regards this proposed system of wiring, it was possible that the Insurance companies might have some objection to the arrangement, but if the matter was thoroughly taken up by the proper authorities he thought there would be no difficulty in getting the necessary addenda to the rules of all insurance companies. This system was recommended for its simplicity, cheapness, safety, the absence of all soldering, and the ease with which extensions could be made if found necessary.

Mr. A. W. HEAVISIDE said that one gentleman had referred to Prof. Silvanus Thompson's description of the ideal tubing, but he thought he had left out the expressions pick-tight and hammer-tight. It appeared to him that the most important thing was the insulation; why trouble about condensed moisture, except, perhaps, in dealing with shipwork? A man who had had experience of shipwork could do almost anything. With regard to the various methods, it seemed to him that everybody was trying to find out which was the cheapest, and we should eventually settle down to three or four types. The greatest problem of all was the bad workman, because his workmanship was bad and he created a bad impression. He not only injured the house, but had no regard for the comfort of the householders. Mr. Heaviside.

Mr. F. LITTLE said he had had a good deal of wiring experience. He noticed Mr. Falconar did not refer to the earthing of any system, particularly of lead-covered systems. It was important, where the ceiling roses and switches are fixed, that the lead covering should be metallically connected by some means. He had used the single lead-covered wire, and he thought it a very good system—especially underneath floors, or in difficult situations where bends were numerous. He was of the opinion that in all cases tubing systems should be properly earthed. A little time ago two men were killed through inefficient earthing of tubing. Had it been properly earthed this would not have occurred. He thought the system introduced by Mr. Bathurst was a very good one. Mr. Little.

Mr. F. T. HANKS said that Mr. Falconar, in discussing gas-barrel, Mr. Hanks.

Mr. Hanks. had mentioned that it had a want of flexibility. If necessary to make this flexible, it required a great deal of labour, which should be avoided as much as possible on account of cost. In regard to internal roughness, this tubing could now be obtained without this disadvantage. It was not a practical suggestion to drive an iron bar through a gas-barrel to remove the internal roughness. He could understand a "rimer" or "cutter" being used for the purpose, but it would be very bad for the "cutter." A man who was a mechanic should not have any trouble in making watertight joints in gas tubing.

He did not understand how Mr. Falconar intended to use spun yarn, asbestos twine, or lead wire in making watertight joints—unless he used lock-nuts.

With reference to internal moisture, a solution of this problem was very badly wanted. The life of a cable was no doubt shortened by water getting into pipes. He could not suggest a remedy, unless it were by lining iron or steel pipes. He thought that, if they were lined, condensation would not be so likely to take place, as moisture did not then come into actual contact with the internal surface of the pipes. The threads which were put on the ends of welded steel tubing were rightly condemned by Mr. Falconar. It was a great nuisance to have to procure special tools in order to get the special threads required. He did not think screwing at all necessary on many classes of installations. He thought slip joints were quite good enough and much less costly in cases where there was no necessity for much strength, and would propose that the ends of the tubes and the insides of the sockets be covered with a hard-drying varnish, This would make a good and lasting watertight joint. There should be no difficulty in obtaining a suitable compound which would ensure an electrical connection through the joints.

At the end of his paper Mr. Falconar favoured armoured cables for use under Class A. What is wanted is a cable which would meet all conditions in practical work, but the difficulty was to get an armoured cable to meet the many requirements. For instance, it would not be at all practical to use steel-taped cable if many sharp bends came into the run, but he thought such a cable would be very serviceable for long runs without many bends. Ordinary wire-armoured cabling answered well for ship work, but it had the objection that if moisture, especially sea-water, got to the galvanized steel wires, it deteriorated them in time, and if examined after a while they were generally found to have become a mass of rust. If armoured cabling were well painted, the paint would afford protection for the iron armouring, and that in turn to the internal part of the cable, and would make a lasting job. With regard to non-metallic tubing, he did not think Mr. Falconar's suggestion to run earthenware tubes or ducts, let into the walls, was a very practical one, and he thought the question would have to be very carefully considered before this suggestion was adopted. Bituminous fibre tubing was, he thought, rightly condemned. It was not a good material at the best, and there was always the likelihood of nails, etc., being driven into it.

Mr. Falconar rightly condemned simplex, or split tubing, as he

called it. He (the speaker) thought if tubing had to be used, it should be welded tubing—not split or brazed. He thought, where stronger mechanical protection was not required, lead-covered wiring was one of the best systems for carrying out an installation, as such wiring could be made watertight more easily than any other system. He had in mind an installation carried out in some extensive greenhouses, where a lead-covered cable system was made absolutely watertight. A twin lead-covered cable was used and worked admirably. The tin-lead boxes into which the wires were brought had the leading-in holes drifted so that the cables fitted exactly, but white-lead paint was applied to the ends of the cables before being inserted. It made a very neat installation, and successfully withstood the water. The fittings, as well as the entrances to the switches, etc., were, of course, made watertight. Mr. Hanks.

He would have liked to see more reference made in the paper to the protection of the conductors at the terminals, where the switches, etc., came, because he thought breakdowns were in most instances caused by faults, etc., at the terminals rather than in the general run of the cables, and he rather wondered Mr. Falconar had not given greater prominence to this point.

With reference to Mr. Falconar's remarks to the effect that a form of armoured cable would at some future time be adopted as a standard, he did not agree with the writer for the reasons stated. He did not think an armoured cable would be manufactured that would meet the many demands which cropped up in ordinary practice.

He was still very much in favour of wood casing for surface work in dry places, but the grooves should be coated with shellac varnish and the casing well painted on the outside. He wondered owners did not take more care of their installations as regards the painting, etc., of casing or cables generally. In many cases the ordinary woodwork was seen to be well painted and the casings, tubes, etc., allowed to go without any such covering.

For Class C Mr. Falconar favoured cleet insulators or lead-covered wires. For his part, although he thought lead-covered wires would make a very neat installation, he would not favour their use on plaster work. He foresaw much trouble in fixing such cables because plugs must be used in many cases. This would be costly as regards labour, and as the cables would not cover the ends of the plugs the latter would look unsightly.

With regard to the question of cost, he did not see why Mr. Falconar made any reference to the value of the material after an installation had been dismantled. If it were foreseen that the installation was to be of a temporary character, very little pains need be taken in putting it up, but care would of course be taken not to injure the material more than could be helped.

Mr. G. Ralph said one of the previous speakers mentioned having used flexible metallic tubing for wiring big engines. It might be of interest to know flexible metallic tubing, made from solid drawn tube, could now be obtained, which was of course impervious to oil and water, and which would therefore seem very suitable for this purpose. Mr. Ralph.

Mr. Woodhouse. Mr. W. B. WOODHOUSE said that the tubing to which Mr. Ralph referred was about twice the price of the ordinary sort.

Mr. Gowdy. Mr. S. H. GOWDY was of the opinion that the time had not yet come for standardisation. Each method had its advantages and would retain them for some considerable time to come, but insulated steel tubing would eventually be adopted, possibly a more flexible tube than we are accustomed to use at the present. He considered that for damp places, lead-covered wires in screwed welded tubes, or lead wires in wood casing painted with shellac, made a very sound job. Non-metallic or papier maché tubing is of little use unless it can be fixed so as to be absolutely free from the joiner's hammer. Ordinary wood casing is not done with yet, and is probably still more used than any other system for protecting wires. Plain uninsulated tubing has both its advantages and its disadvantages. In case of the former, should a short circuit occur between two wires of opposite polarity they will probably burn themselves out and prevent any further danger; whilst, in the latter, dampness is not easily got rid of, thus increasing the trouble of earth leakage, the sweating acting upon the insulation detrimentally. Professor Silvanus Thompson had defined an ideal system in a nutshell when he said it should be electric-tight, water-tight, air-tight, gas-tight, oil-tight, and rat-tight. Therefore, what is required is a perfect insulator mechanically strong and impervious to moisture, acids and alkalies of cements and plasters used on buildings. With reference to the estimates and cost of the different classes of tubing and casing mentioned in the paper, he would like to have fuller details as to what they include, and how Mr. Falconar arrived at them, as the price seemed very high in some cases. He was of the opinion that screwed welded steel tubing was the only satisfactory tubing yet introduced, though it was more expensive both in first cost and in erection. He considered there were far too many different patterns of tubing accessories, and that there was a great want of standardisation both in these and in the sizes of tubing itself, and in support of this gave some details extracted from lists of various manufacturers who seemed to vie with each other as to which could provide the largest instead of the smallest number of fittings. Some made use of outside dimensions, while others only gave internal measurements, while others again listed their goods alphabetically.

Mr. Gott. Mr. A. E. GOTT said that there was no doubt some form of piping system would be the system of the future. If there were multiple control and separate wires going to every lamp in the place, these wires would have to cross each other, which would add to the difficulties of installation. The weakness of any pipe system was the absence of any recognised method of running pipes along the wall and under the floor. The boxes of all these pipe systems seemed to be too shallow. Pipe systems to be satisfactorily installed should be let into the brickwork before the plaster was laid on. Lead-covered wires had failed in many installations because pure lead was used. Some lead alloy was wanted to replace the silver in the old-fashioned lead. A large firm of shipowners had taken out their entire lead-covered installations on board their ships, and had used vulcanized wire with great success.

He remembered the first system he installed, where the conductors were buried in fireclay—to prevent them taking fire. They also used casing three sizes too large. This was done most religiously. The system was still running and there had not been a fire. Mr. Gott.

The success of any system depended largely on the question of labour. The electrical trade suffered from imperfect labour. Every man who was a failure in every other trade came to them, and thus jobs were spoilt by ignorant men. He remembered the case of some bad work on a ship. The cables were run along the lower deck, were plain cotton covered without rubber or compound, and every time a sea came down the companion-way there was a short circuit. This vessel, which was an oil-tank vessel of the old type, was destroyed by a terrific explosion, and a man who was in the hold at the time had not been seen since. There was no doubt a spark caused all the trouble.

Mr. C. F. PROCTOR said the question was really one of cost. He believed that a cheap quality of iron pipe could be obtained from manufacturers. He was also of the opinion that the architect was the cause of much of the trouble, as he did not take into consideration the wiring when designing the building. He knew of several cases where great and unnecessary expense had been caused through this oversight, no attention having been given to how pipes could be run without encountering thick walls, thus leading to the making of numerous bends and joints which might have been avoided. On the whole, he thought the iron pipes one of the safest and best methods. Mr. Proctor.

Mr. R. ROBSON said wood-casing was very hard to beat for old houses, and it was certainly the thing for the poor man's house because of its cheapness. Mr. Robson.

Mr. A. W. HEAVISIDE said it was a very important question, as where a public supply company expended capital to the extent of £100,000 the public had to spend £50,000 on fittings, and that was not in the case of a well-developed company. For every £100,000 spent by the company the public would probably have to spend an equivalent amount in the wiring of their houses. Mr. Heaviside.

Mr. FALCONAR, in reply, said: The Chairman, at the last meeting, made some comments on the tubing system. He would like to know a little more about the method of drawing the tubing exhibited. Was the steel covering drawn on cold? [Mr. Holmes: "Yes."] Mr. Holmes also made some remarks about the methods of jointing proposed. With regard to asbestos twine, the idea was to wind it after the tube had been screwed; if wound round the thread before sockets were screwed on a fairly good watertight joint was obtained. Mr. Woodhouse confirmed his remarks about simplex tubing; he also advocated ceiling roses without blocks. The worst part was where the wires were run under the ceiling rose; he had seen several ceiling roses made with grooves or holes going through the porcelain base. With regard to lead-covered wiring in flexible tubing, he had not tried it, but imagined the lead covering would give way. Mr. Falconar.

He had some very scathing remarks to make to Mr. Sleigh, who rather took the wind out of his sails by bringing a sample of standard

Mr. Falconar.

tube, from which he demonstrated that the apparent discrepancy in his remarks was due to the present imperfect method of measuring gas tubing. Mr. Sleigh recommended taped wires. He had tried these once, but they were not very successful. The tape did not seem to be sufficient and moisture got in.

Mr. Little made some remarks about earthing, and he entirely agreed with him that any metallic tube system should be continually earthed through the entire length.

He was obliged to Mr. Hanks for his long criticism of the paper. With regard to the method of producing a smooth interior in the tubes, he did not see how Mr. Hanks could get a cutter or rimer right through a long tube.

With regard to jointing tubing, his reply to Mr. Holmes applied to Mr. Hanks as well.

With reference to sleeve-joints, these would certainly be very good where the piping was rigidly fixed, but he found them in most cases apt to work loose (there was a sample on the board).

With regard to the sketch on page 841, it was not meant to represent petticoat insulators; they were bobbin insulators, and were for inside, not for outside use. Mr. Hanks mentioned something about junction-boxes lined with mica, but he had not had a very satisfactory experience with it, as it absorbed moisture.

Regarding waterproof casing, his idea was to prevent the water from getting in. He agreed with Mr. Hanks that good insulation was obtained when the casing was shellac-coated, with a coat of paint over all. In one case he had in mind the test came out excellently, although the building was very damp.

The value of old materials was a point to be considered. If the wiring could not be taken out, or was worthless when this was done, the user would have to write off a large amount of the cost as establishment charges or otherwise. If there was some method by which wires could be taken out easily they would then make a valuable asset. Mr. Gowdy evidently thought screwed tubing the best. He would like to know what sort of tubing Professor Silvanus Thompson suggested after giving his definition of his ideal conductor.

With reference to Mr. Robson's recommendation of wood-casing, his attention had been called to some remarks on this subject in the *Electrical Review.* He was gratified to see they considered his paper deserved the careful criticism they had given it, which, on the whole, was favourable, but they mentioned he seemed to have a soft corner in his heart for wood-casing. His experience of wood-casing had been the same as Mr. Robson's, very favourable. They also condemned him for having divided his subject into more than two classes; one class, the worst, was the only one necessary. But if you were to do that, it meant practically abolishing the electric light from half of the consumers who could not afford to pay the cost of wiring for this class.

With regard to damp caused by bad state of property, this was a matter for the property owners to attend to.

NEWCASTLE LOCAL SECTION.

SOME NOTES ON CONTINENTAL POWER-HOUSE EQUIPMENT.

By H. L. RISELEY, Associate Member.

(*Paper read at Meeting of Section, February* 16, 1903.)

In response to your committee's invitation to submit a paper to the Local Section, I have thought that a few notes on the subject of Continental power-station practice gathered during a visit to the Continent last September might be of interest, especially to those who agree with the writer that there is much to be seen worthy of consideration, if not imitation—of course, subject to improvement. Some little interest may also be attached to a few of my notes in view of the Institution's Continental trip this spring.

On first entering a Continental power-station, one is struck especially by the apparently extravagant amount of space which the switchboards and accessories occupy in the majority of central stations abroad. On closer inspection and consideration one finds that this is not without an object; the object being primarily to provide for any contingency which may arise, and always to provide a duplicate method of operating in event of any part of the switching apparatus being deranged by accident.

A system nearly approaching the ideal was represented, in my opinion, by the central station at Paderno, twenty miles from Milan, which may be of interest, as it is to be visited during the Italian trip of the Institution next April. There are seven turbine water-driven generators, having a capacity of 2,160 H.P. each, and the machines a capacity of 1,590 k.w. each, speed of 180 revolutions per minute, frequency 42 per second, 13,500 volts. The current generated by the alternators at Paderno is collected at the 'bus-bars, and thence led to the high-tension transmission line without the intervention of any transformers. At Milan the line ends at the Porta Volta station, where the pressure is transformed down to 3,600 volts, and at this station steam-driven generators are running in parallel with the transformed current generated at Paderno (Fig. 1).

The switchboard at the central generating station at Paderno is arranged in a large central opening in the wall, covering an area of 1,750 square feet (Fig. 2). The apparatus for controlling the generators is divided into nine panels, seven of which are for the seven generators, and the two panels in the centre serve for collecting the two sets of 'bus-bars and for placing wattmeters, etc. The attached sketch shows a complete diagram of the generator switchboard, board for the trans-

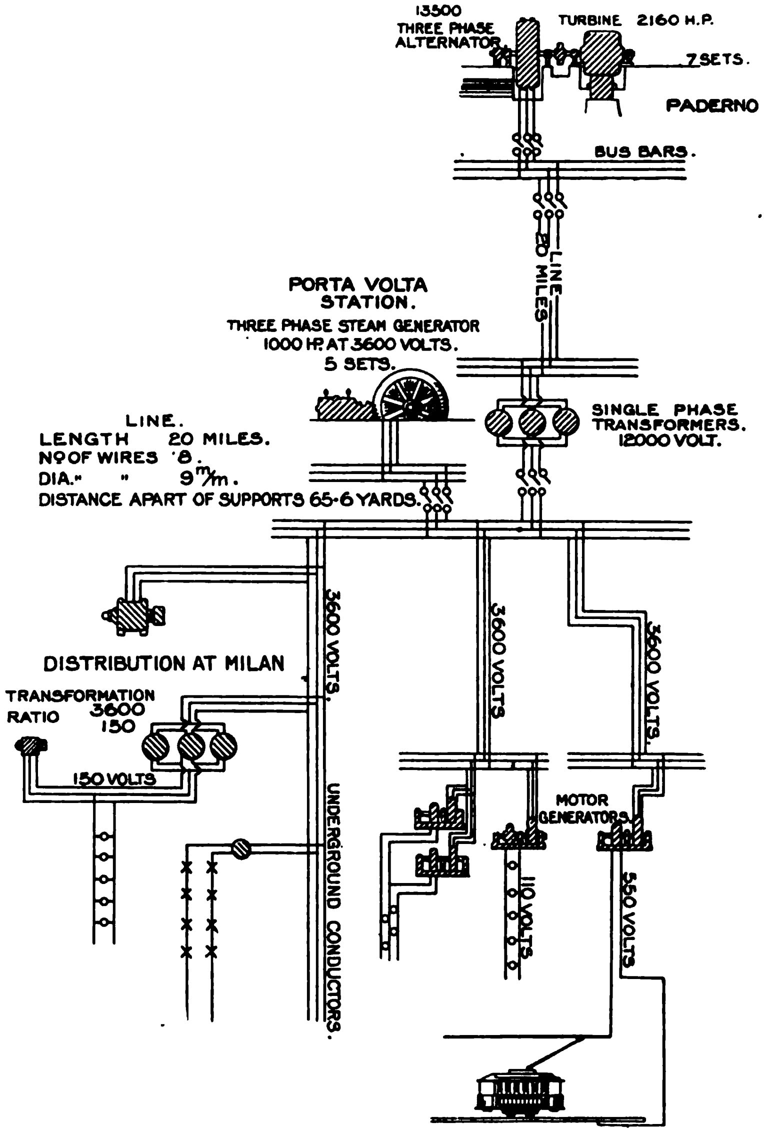


FIG. 1.

mission line, and feeder panels at Milan. Each of the generator panels comprises one triple-pole oil-break switch, three fuses, one linking-up device, one rheostat for field, one rheostat for exciter, one instrument transformer, one voltmeter and indicating wattmeter, one synchronising voltmeter and lamps. All the machine rheostats can be worked in

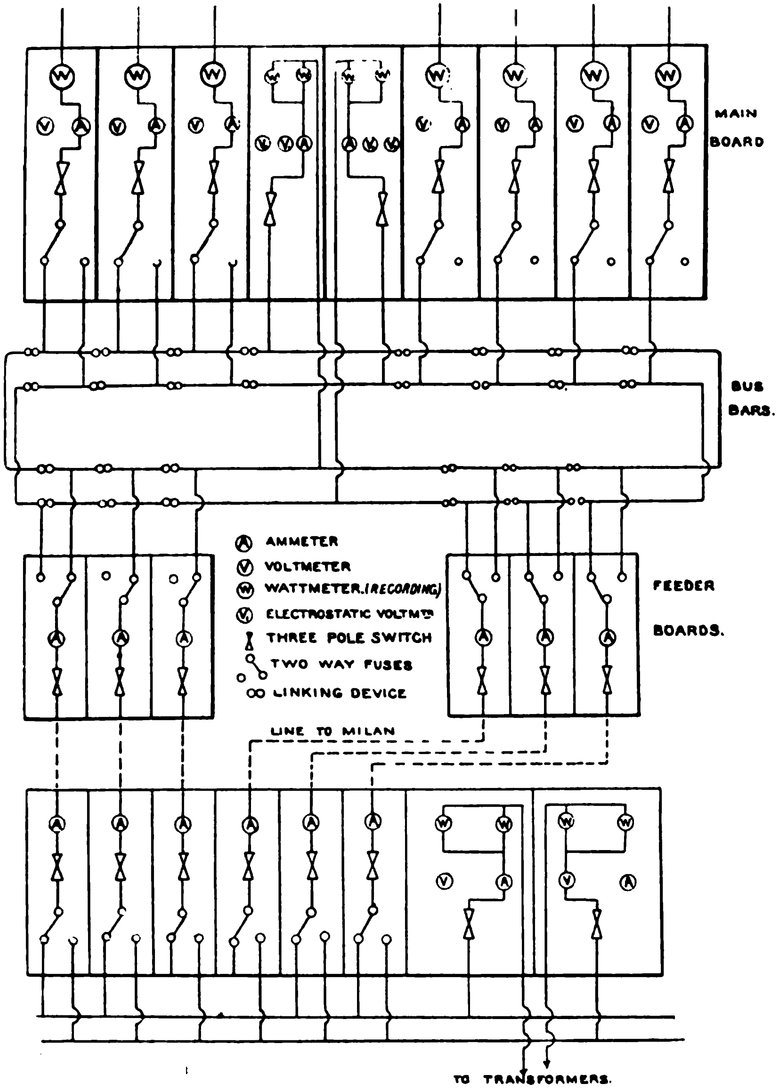


FIG. 2.

parallel or not as desired. The link devices serve the following purpose: The whole of the installation from Paderno to Porta Volta, the auxiliary generating station at Milan, and sub-stations had to be arranged so as to enable the two services to be separated at any moment into two distinct systems. For that reason the 'bus-bars are arranged in two groups, and each generator may be switched on either group;

in that way the lines can be separated. The steam plant at Milan and the generators at Paderno can also be separated. It was also arranged to provide for the possibility of separating one of the services from the other, in case that service should have any special requirements on account of its disturbing influence on the other services. However, the experience at Paderno has proved that it has not been necessary to separate the two services. Behind the series of high-tension generator panels are arranged in another room the high-tension transmission line boards, each line having a special switchboard, with switch, link device, voltmeter, and ammeter. All the switchboards are extremely accessible. Each panel may be entirely separated from the live ones, so that it may be attended to and cleaned by the attendant in perfect safety. The panels are, as usual in Continental practice, made of marble and porcelain fixed on iron supports, no combustible material being used in their construction. The connections are all rigid bars, and the whole is a perfectly symmetrical, simple, and extremely mechanical job. The high-tension transmission lines, before taken out, are led into the floor above, in which are arranged the lightning arresters. Thence they pass through holes in the wall to the first pole. The lightning arresters are of the usual Wurz type, and comprise a number of cylinders made of special brass containing a large quantity of zinc, arranged so as to leave about 0·04 in. gap between each cylinder.

In my opinion the advantages of this type of board are its extreme accessibility and safety in having, so to speak, another way round, everything being in duplicate. Each portion of the apparatus can be made dead for cleaning or overhauling purposes without the slightest danger of interrupting the supply. The type of board which is the favourite in this country for high-tension alternating work is sometimes referred to as the multicellular type. The chief faults in connection with this type of board are that it is too cramped, the 'bus-bars being far too close together, and there being no second way round. Also, it is very difficult to keep clean, as the insulators at back of 'bus-bars get covered in hot engine-rooms with a greasy deposit of dirt, which it is impossible to remove by means of air blast, and it is obviously not very safe to try and clean a live board by means of dusters, etc., as you then stand a good chance of starting an arc between two bars, besides being a danger to the man employed. Again, the switches are too cramped. It is not an uncommon thing for the switchboard attendant when about to synchronise to put the switch a shade beyond half-cock, and to make contact to the bars with disastrous results.

Kander Power-house.

As the first full-gauge electric railway was supplied from this power-house, I think a short description will be of interest. It is situated near the junction of the Kander with the Simmen, quite close to Lake Thun, and was entirely equipped by Messrs. Brown-Boveri. Its primary object, as stated, is to supply power to the Burgdorf-Thun line. At present about 3,600 H.P. are converted into electric energy, but

provision has been made for increasing the capacity of the station to 4,500 H.P.

The power-house is situated on the bank of the lake, and is 108 ft. by 37½ ft. wide, and has room for six turbines and generators—up to the present five have been installed. The turbines are by Girard, of 900 H.P. each at 300 revolutions per minute, and the speed can be regulated by hand or automatically. The three-phase generators are connected direct to the turbines, having each a rotating field spider with 16 poles, and develop each 620 k.w. at 4,000 volts. The drop is 18 per cent. up to 115 amperes at 4,000 volts on an inductive load, necessitating an increase of 38·7 per cent. in the exciting current. In view of the fact that the whole output of a machine has to be used at times on a single-phase lighting circuit, they are designed in such a manner as to enable them to develop their full power of 620 k.w. at 4,000 volts as single-phase machines. In that case, with a non-inductive load, the drop amounts to 9·1 per cent. Each of these generators is separately excited by a four-pole exciter of 12 k.w. at 60 volts, the armature of which is mounted on the main shaft. These direct-current machines for exciting the three-phase generators receive in their turn current for exciting their fields from two other direct-current machines separately driven by turbines each 20 H.P., developing 14 k.w. at 125 volts at 850 revolutions per minute. The reason for this indirect way of exciting is that the fluctuations in the speed of the main turbines, due to the variation of the load on the generators, have less influence on the pressure than if the field of the exciter was to decrease simultaneously with the speed of the generators and exciters. The field regulation of the generators can be effected either separately or in two groups or else all together, as desired. It is done entirely by means of the secondary exciting circuit. Any alteration of the resistance in the circuit of the secondary exciting machine is avoided by suitably arranged rheostats, which are switched on automatically during the regulation, so that in any case these secondary exciting machines always remain under constant load both during the regulation itself and after switching in and out of the fields of any number of generators. As the current to be supplied by these secondary exciters does not exceed six amperes, it was possible to arrange the rheostats very neatly. The shunt-breaking resistance of the exciter switches was arranged with an adjustable air-gap. The terminals of the generators are coupled up by small cables, arranged in small tunnels which are quite accessible to the main switchboard, which is of the usual Swiss make with a facing of white marble.

The main switchboard itself is in another room adjoining the main building, 50 ft. by 15 ft., and is supported from the ground on rolled-steel joists about 9 ft. 6 in. up. On this board, which fronts the engine-room, are fixed all the necessary instruments and regulating resistance wheels, switch levers, etc. At the back, in the other room, under the floor, are arranged the 'bus-bars to which are run the generator cables. There are no 'bus-bars fixed to the switchboard itself, and all conductors on any panel may be disconnected from the 'bus-bars by removing the links at floor-level. The 'bus-bars are

divided into two sections, so that it is possible to operate two circuits, which are called steady and unsteady. The two sets of 'bus-bars are arranged in a circular fashion, so that either can be closed or open at certain points. In this way it is possible to work the two circuits either separately or together. At the time of my visit the bars were divided, the unsteady service supplying current to the Burgdorf-Thun line, the other supplying all the rest. Arrangements have been made to enable the two circuits to be worked together in case of any breakdown of apparatus. The central panel of the switchboard contains a switch lever for connecting the two 'bus-bar systems. The regulation of the two separate services (which was extremely arduous, due to the great head of water, and being unable to govern well) is affected according to the requirements, as shown by the two 'bus-bar voltmeters arranged at each end of the switchboard. In order to enable the generators to be used in any desired combination for the joint or separate working of the two services, the driving devices for the regulating rheostats are capable of being coupled up all together or in two groups as desired, so that they can be operated by the two large hand-wheels directly under the voltmeters. Adjoining the generator panels at each end is a panel for connecting the two sets of 'bus-bars with transformers which transform the pressure from 4,000 volts up to 16,000 volts for transmission. Places in the immediate neighbourhood are supplied direct from the 'bus-bars at 4,000 volts.

Under the switch-room is a transformer-room, in which is an overhead crane, which can be travelled into a repair shop. The transformers on being taken out of the repair shop are lifted on to a bogie car on rails, and are transported along rails laid across the whole transformer-room to their place. They are slid off the bogies on to rolled-steel joists sunk into the concrete, just projecting about ¼ in., and thus it is very easy to change the transformers in case of any breakdown. They do all their transformer repairs at this station. At each side of the transformer-room there is space for nine transformers. Up to the present only eight have been installed. They are single-phase transformers immersed in oil, and water cooled, capacity of 300 k.w., the efficiency being 98 per cent., star connected. Four of these transformers are on the steady circuit, two of which are devoted entirely for lighting and are operated in parallel, being connected to the single-phase circuits. The other two are used for power. The other 'bus-bar system, called unsteady, has three transformers coupled up with a fourth in reserve, which is capable of being switched into any desired phase by means of special switches in the primary and secondary circuits.

All conductors, including the high-tension conductors from the terminals of the transformers, are taken through the ceiling into the transformer switch-room situated above. Insulation through the floor is ensured by very thick glass tubes about 20 in. long. In the transformer switch-room are arranged in a clear and easily accessible manner all the switch levers and instruments for the primary and secondary circuits both for the transformers and transmission line. The 'bus-bars of the two services are each led along the longitudinal

side of the room, and the switch apparatus for the primary circuit of the two groups of transformers is accordingly arranged at both sides of the room, being separated in accordance with the two services. Each transformer has a switch panel of its own, containing oil-break switch, ammeter, and fuses. Opposite these, in the centre of the room, are arranged 'bars and switches for the high-tension circuit of the transformer. The high-tension fuses used on these consist of aluminium fuses in the usual Brown handle. The latter are surrounded on four sides with slate division plates, the front being protected by a removable grating. All the switches and instruments of the 4,000-volt circuit as well as the 16,000-volt circuit are arranged, not on switchboards, but on light, open steel structures, of course everything being well supported on insulators. From the high-tension 'bus-bars of the two banks of transformers are run two sets of conductors (bare) to the distributing board for the overhead line, the front of which is a marble panel arranged on a raised platform on the north side of the room. The latter 'bus-bars are also divided into two sets, which make another ring circuit same as before, or may be separated from each other at different places, so that the separate feeders may be switched on to any of the two services. Each panel contains fuses, an ammeter in each phase, as well as a three-pole oil-break switch. All switches are mounted well above the panels in order to avoid any arc, if any should be formed jumping across from the bars underneath. The switches are all worked by levers, either by means of a chain or rope. From the feeder 'bus-bars wires are led into the open through holes in vertical marble slab, being also insulated by very thick glass tubes. Altogether there are 14 cables led away by the overhead line. Three branch away immediately on leaving the power-house, and are for local consumers in the immediate neighbourhood; these are at 4,000 volts. The remainder, being ¼ in. diameter, carry current at 16,000 volts, and are carried as far as Thun on iron lattice columns. The insulators are secured in two groups by means of bolts and lock nuts to vertical wooden supports (creosoted), secured to the iron frames at the top of post at a height varying from 28 ft. 6 in. to 39 ft. 6 in.

Three lines are utilised in working the Burgdorf-Thun line. Three go to Burgdorf; five to Berne, two single-phase and three three-phase. The iron posts, which are fixed in blocks of concrete in the lake itself, are all connected with the earth by a wire passing under the high-tension line. At certain places, especially at curves and railway crossings, the construction is a little heavier. The insulators are of a special type, 6¼ in. long, with a double petticoat 4¼ in. deep. This line ends at Thun in a distributing tower, and from this point the lines are carried on timber poles from 25 ft. to 46 ft. in height. As said before, five of these lines go to Berne; of the remainder, three go to transformer stations for the railway and the other three to Burgdorf, all supported on poles. In the event of a low-tension wire snapping or springing up against the high-tension lines, all chance of danger is obviated by the fact that the wire would come in contact with the earth-wire first.

The distribution in Berne takes place from a closed-ring circuit formed by the five wires, and surrounds the whole town, to which circuits are tapped on four transformer stations. These sub-stations are arranged in double-storeyed buildings of about 265 square feet area, and consist of a front room, which is utilised as an erecting shop and provided with a travelling crane. The transformer-room adjoins this, and the switch-room is overhead. There are four transformers in each station, although the buildings are designed to take seven, each having a capacity of 50 k.w., and are immersed in oil and water cooled. The leads to the transformers come from the switch-room overhead, along whose walls is arranged all the switching apparatus, high-tension one side, low-tension the other. The switches, fuses, ammeters, and lightning arresters are arranged on identically the same lines as at the central station. The ring circuit can be disconnected from the transformers by means of two special switches arranged close to the spot where the high-tension lines enter the building. These switches are operated by long levers outside the building, so that the portion of the ring circuit situated between two substations may be deprived of the current without necessitating entering the transformer stations and interrupting the working. The pressure is reduced by transformers to 3,000 volts, and the current passes from the secondary 'bus-bars to the underground cables supplying the town. Inside the town the pressure is reduced to 250 volts for driving motors, and to 125 volts for single-phase lighting. At Burgdorf, which is the second distribution centre, the voltage is reduced by two transformer stations from 16,000 volts to 500, and the power is used for driving large motors. For working the smaller motors, as well as for lighting purposes, continuous current is used. This is obtained by two motor-generators which convert 500 volts three-phase to 150 direct current. This energy is distributed by a three-wire system and by two batteries of 840 ampere-hours capacity.

The operation of this installation presents, of course, special difficulties, on account of its being necessary not only to supply a large amount of current for lighting and power purposes only, but also at the same time to provide for extremely large variations in the power required for the railway traffic. In order to prevent these fluctuations from affecting the remainder of the system, the installation is arranged for working two entirely different services. A good idea of the variation may be gained from the fact that it is by no means exceptional for the railway to suddenly take for a more or less considerable period as much as 1,200 H.P. To sum up, the special points to my mind worthy of attention are that the 'bus-bars are arranged exactly as a ring main in a boiler-house. Four of the generators may be switched into one or the other feeder circuits as desired by means of the ordinary switches. The various duplicate 'bus-bars on the generator switchboard in the transformer switch-room, as well as on the feeder switchboards, are all arranged as ring circuits, which, by removing or closing linking devices, can at any moment be divided into any desired section, so that in this way all kinds of combinations in working can be readily effected. The transformers

used are all single-phase, which allow in case of any of them getting out of order to switch in at once a reserve transformer into the corresponding phase. These single-phase transformers enable the output of one phase to be increased by switching in further transformers, which, as in this case, where the whole lighting circuit is connected to one phase, is of special importance for the regularity of the supply. Finally, the whole line is arranged, especially as regards switchboards, with ample room everywhere, so that the extra high pressure does not in any way interfere with the reliability of the system.

Valtellina Line.

A short account of the Lecco-Colico railway may be of interest. I found that although the line was equipped as far as Lecco, starting from Colico, that at that time there was no regular service running, as only experimental cars had been run up to the time of my visit. As is well known, the system is three-phase, with the overhead line at a potential of 3,000 volts. The power is primarily generated at Morbegno at a pressure of 18,000 to 20,000 volts direct. The plant consists of three 2,000-H.P. generators running at 150 revolutions per minute, 15 cycles, having a capacity of 1,300 k.w.; exciters on turbine shaft end; voltage of exciters, 45. The machines are extremely well ventilated and the windings on the machine spaced widely apart.

There are practically two sets of main high-tension 'bus-bars, and each generator feeds into both through high-tension circuit breakers. Each generator has one ammeter, wattmeter, and synchronising voltmeter and lamp; the pressure on the instruments is reduced by static transformers. There are six lightning arresters, three to each set of bars, one arrester being placed in each phase. The high-tension switches are identical with the old Siemens lightning arresters: on opening the contacts the arc forms between the nearest points of the horns and travels upwards, due to the heated air, until it breaks. The current is conveyed from the power-house by means of a transmission line to nine sub-stations situated at the side of the track; at these sub-stations the pressure is reduced to 3,000 volts, which is carried on the overhead line. With one exception only, the sub-stations each contain one three-phase static transformer of 300 k.w. normal rating, but capable of working for a short time up to 900 k.w. One of these nine sub-stations contains two such transformers. The cooling apparatus consists of a small blower driven by an induction motor. The transformer sub-stations are separate stone buildings alongside the railway stations, the transformers being placed in a specially locked room, which is inaccessible to the ordinary railway officials.

The transmission line, at 18,000 volts, runs parallel to the railway a short distance away, but, of course, does not run through the tunnels, of which there are a great number, but over the mountains. Nor does it run through the stations, but at some distance from them. Lightning arresters are placed on the primary line every three miles, and on the secondary every 1¼ miles. The secondary leads are spaced 60 cm. apart, the primary at 87 cm. The secondary is an

ordinary trolley wire, and the primary varies in diameter according to the amount of current it has to carry. A separate span wire is always used for each phase, and double insulated. Of course, the rails are used as a return. All the rails are bonded with ordinary trolley wire, only instead of the pin being solid it is hollow, and collapses when being driven in, and in no case has trouble been experienced through defective contact. Originally the railway company insisted on protected bonds being used, and these were tucked away at the back of the fishplates; but after two years it was found that 10 per cent. of these had got broken, so the plan was abandoned, and the bonds put in an unprotected manner, and just buried in the ballast. Since doing this no further trouble has been experienced. The track is also cross-bonded at about every 300 yards.

On making a trip on the track, I found that the acceleration was extremely even, there being no jolting whatever. The starting resistances on the car consist of water in a tank with fixed plates, the level of the water being raised or lowered by compressed air, which is also used for the Westinghouse brake, the whole apparatus being worked by a small valve in the driver's compartment; the time occupied to take out all the resistance varying from 16 to 60 seconds, depending on the weight of the train, gradient, etc. The air-compressor is driven by a small motor with an automatic switch, which stops the motor when there is sufficient pressure in the tanks. The trains take up to 90 amperes at 3,000 volts to start up, this being the maximum, and from experiments a train on a gradient of 17 in 1,000, with a draw-bar pull of four tons, got up to speed in 37 seconds. There are loop lines on the overhead line through the stations which are made dead as soon as the train comes to a standstill; also the trolley boom is lowered, this being also operated by compressed air, and in the event of a car standing for a long time, there is a small hand-pump to get sufficient air pressure to raise the trolley to get current in order to start up the motor for the air-compressor. The air-compressor also works the whistle.

There are two ways of lighting the trains, either with accumulators or else by means of transformers and lamps with three filaments at 100 volts 15 cycles. A small 8-k.w. transformer supplies current for the lamps, motor, compressor, and heating. The flickering of the lamps was hardly perceptible, more especially those behind ground glass. The same system of lighting was employed at the stations. The main switch on the car was operated also by compressed air, and there was an interlocking arrangement, by means of which it was impossible to get at the switch if the trolley was up, and, of course, impossible to put the trolley up if the switch was open. The trolley was of novel construction, consisting of a copper pipe running on roller bearings, and the whole supported on a wooden shaft. These trolleys have run 30,000 miles without being renewed. The cars are mounted on two four-wheeled bogies, each of which has one primary and one secondary motor mounted direct on the axles. They weigh about 50 tons, and can seat 56 passengers. The locomotive gave a draw-bar pull of 10,000 lb. at 19 miles per hour. The body of the locomotive is

mounted on two four-wheel trucks. Upon each of the four axles a motor is directly mounted, no gearing being used.

All motors are primary, and speed regulation is obtained by using either one, two, three, or all motors to suit the conditions. The rotor shaft, which is hollow, is connected to the car axle by a flexible coupling. The coupling is balanced by counterweights, by this means, although running in fixed bearings can drive the wheel, at the same time allowing the wheel and axle to rise and fall with the inequalities of the road, only $\frac{5}{32}$ths clearance being allowed on the rotor. The average speed is fairly high, as the acceleration is very rapid, although the maximum speed is not excessive, it only being 60 k.m. per hour. They were able to coast above synchronous speed down hill and they coasted below synchronous speed on the flat. The two most efficient speeds were 30 k.m. and 60 k.m. per hour. The whole scheme, including power-house, water power, and canals for same, work out at £4,500 per mile.

On carefully considering the design of the foregoing power-houses and equipment, it seems to me that two things have especially been aimed at—viz., simplicity of design, and a duplicate arrangement of all gear as far as possible. In getting out designs for new power-houses engineers generally consider, in regard to the relative capacity of engines and generators, that the most economical load for the engine shall be that of the maximum load of the generator, and they arrange that, by lengthening the cut-off on the engine, the generators shall be capable of being greatly overloaded without reducing the speed of the engine. In the new power schemes that are before us to-day, where it is absolutely necessary to keep up an uninterrupted supply, it is necessary to take all precautions possible to keep the station 'bus-bars alive at all times and at all costs, notwithstanding any local disturbance which may be taking place outside the control of the power-house. The general source of trouble is fuses, more especially now that much heavier feeders are in use than formerly, so that sometimes when a feeder is shorted it causes an immense amount of trouble by fuses not blowing at the proper time, more especially if the fuses on a system are of different design; also, fuses do not always clear themselves and thus blow the generator fuses, so that endless trouble is caused. By making all the steam plant identical and of sufficiently small capacity, so that in case of a heavy overload it will slow down, all fuses and automatic circuit-breaking devices on the generator panels may be avoided. In the event of a short occurring on a long-distance high-voltage transmission line, the fault would almost immediately clear itself; if not, the engineer in charge will probably notice a different hum in the machines, and will probably have noticed one particular feeder taking an abnormal current, or else that the speed has dropped, and will immediately open the faulty feeder. In case of a continued short-circuit, the lower voltage limits the power which can flow through a fault. By this system any interruption to supply would probably be of very much shorter duration than if fuses are to be replaced and the automatic circuit-breakers closed, after a general opening of all these devices. Of course, there is the risk of all the motor-generators and

rotary converters dropping out of step, but I have known cases where motor-generators have kept in step even with a variation of 20 per cent. in the speed of the generating plant.

Mr. Stewart. Mr. ANDREW STEWART (*communicated*): The first point which caught my eye as I read Mr. Riseley's paper was the amount of plant in the Kander Power-house, some 3,720 k.w. on an area of 4,080 square feet, or 1·1 square foot per kilowatt. This is a figure which, although it has been improved by some of the high-pressure water-power plants employing Pelton wheels on the Pacific coast, is nevertheless a good example of a Continental water-power plant with a medium fall. Having beside me a few figures for power-houses in New York and Berlin, I give them below, with the relative position of the boilers and the type of engines, all of which influence the area required per kilowatt.

Name.	Total K.W.	Area of Ground, Square Feet.	Square Feet per K.W.	Arrangement of Boiler.	Type of Engines.	Size of Unit.	Revs. per Minute
Metropolitan, N.Y.	38,500	48,800	1·26	On 3 floors	Vertical Cross Compound	4,500 h.p.	75
Kingsbridge, N.Y.	78,830	56,000	1·4	On 2 floors	Vertical Cross Compound	4,500 ,,	75
Manhattan, N.Y....	82,416	40,000	2·05	On 2 floors	Duplex Compound	8,000 ,,	75
Oberspree, Berlin	43,000	280,000	6·5	On 1 floor	Horizontal triple Gorlitz	1,000 ,, 2,000 ,, 3,500 ,,	83
Moabit, Berlin ...	33,000	363,000	11·0	On 1 floor	Horizontal triple Sulzer	3,500 ,,	83

Mr. Stewart.

Oberspee and Moabit will have all extension units of 6,000 H.P., and figures given are based on ultimate capacity of station when buildings are full.

The German H.P. is 1½ per cent. smaller than the English, but that does not materially alter the figures. On my visit to the Berlin stations some months ago neither had reached its full capacity, but there was no evidence in either case of economical tendencies as to ground space, chiefly because ground was very cheap, each station being located some miles from the centre of the city. The figures probably represent the extremes of large power-station design, as even in London the area per kilowatt of any of the stations is not much less than that of the Metropolitan Station, New York, although in conversation with the engineer of one of the new underground railways for London I learned that with Parsons turbine units it was hoped to get the ground space in one power-station down to one square foot for each kilowatt installed.

Mr. Riseley's reference to the transformation of three-phase currents by three single-phase transformers is also interesting, instead of the more usual Continental plan of employing three-core transformers for this purpose. The ease with which another single-phase transformer may be switched in to replace any one of the three should it happen to break down, is not sufficient to justify the extra capital expenditure, which may be 10 to 20 per cent., depending upon the size. In addition to this, I note that a good proportion of the power at Berne is used as single-phase, where of course there will be some tendency towards unbalancing. This tendency can best be checked, if not quite suppressed, by the use of three-core transformers, the interaction of the three phases being sufficient for this purpose. If Mr. Riseley has heard this point raised at Berne, perhaps he can throw some light on it.

Another interesting point is the Lecco-Colico line, where it appears that 15-cycle 3-phase currents are employed throughout. It would be interesting to know what considerations led to the choice of this low periodicity; certainly the motors and transforming apparatus would cost a good deal more than with a higher periodicity. One consideration which appears to justify this low periodicity would be the greater apparent resistance of the rails with currents of a higher periodicity. If the rails have a large section, this would probably become a matter of considerable importance, but it is doubtful if it was the reason for the adoption of a periodicity of 15 cycles. Perhaps it may have been due to mounting the motors direct on the axles, and using driving-wheels of small diameter; this, with a small number of stator poles, say four, would correspond to the higher speed mentioned by Mr. Riseley, viz., 60 kilometres per hour, but this would involve wheels approximately 30 inches diameter, and it is improbable that the motors could be mounted directly on the axle in the space available. There must of course be some good reason for such a departure from recognised practice. Another point is the statement that each bogie on the cars has two motors, one primary and one secondary; this would lead one to suppose that they are arranged permanently in cascade, which seems unlikely, unless when running at 30 kilometres per hour, while the next paragraph says "all motors are primary." It is difficult to reconcile

Mr. Stewart. these two statements, as they indicate directly opposite practice, and I should like to have Mr. Riseley's views.

Mr. Woodhouse. Mr. W. B. WOODHOUSE was interested in comparing the methods adopted for the protection of the system in the stations described with those used in other countries. He noted that the use of fuses was general, but he was surprised to find aluminium fuses still in use. Aluminium had been used because its specific heat was large, and it was possible, by carefully proportioning the cooling surface, to make such a fuse act as a time-limit cut-out, but the difficulty of making a good connection had caused most engineers to abandon its use in favour of tin, to which copper connecting strips were sweated. Modern practice in this country and in America was to abandon fuses altogether in favour of automatic oil-break switches; feeders were protected by overload time-limit switches at the generating end, and overload and non-return power switches at the receiving end. He did not consider automatic switches or fuses necessary on generators, an oil-break switch being sufficient, if properly enclosed in an iron box; he quoted a case of such a switch repeatedly breaking 12,000 kw. at 45,000 volts without damage. With regard to a suggestion of Mr. Riseley's, that small engines should be used which would pull up on a short-circuit, the speaker could not agree with this rather primitive method, as all the synchronous sub-station machinery would undoubtedly fall out of step. An automatic switch was the proper thing to use.

Mr. Stoney. Mr. G. G. STONEY said he was much indebted to Mr. Riseley for his paper. It enabled us to compare our systems with those of our Continental competitors.

When he was over in Germany the thing which struck him most was that the capital expenditure was excessive, especially for buildings. Take two modern stations. The style of buildings would never be countenanced in this country, and the space occupied by the plant was excessive. It was 1½ square feet per kilowatt, without taking into account switch-room. If the switch-room were taken into consideration it would work out at 1¾ square feet. The space used was 1⅛ at Neptune Bank. In one station £130 per year was spent on washing floors. The result of this excessive expenditure would be disastrous at some future time. The charge for current was higher than it was in England, being as high as 7d. and 8d., whilst in Newcastle it was 4½d.

His opinion was that for real sound work England was far ahead of the Continent. He quite agreed with Mr. Woodhouse that fuses were a great nuisance. He would be inclined to do away with fuses, especially main fuses, on machines. Fuses of aluminium in china handles, of the Brown-Boveri type, seemed to work fairly well.

Mr. Vesey Brown. Mr. C. S. VESEY BROWN said that one envied the French, Swiss, and Italians in the possession of their magnificent waterfalls, and unfortunately the conditions in England were so different that manufacturers and others connected with central stations were obliged to use steam to compete with their Continental neighbours. He did not know of any other water-power station than that of Reinfelden, in Germany, where most of the stations were steam-driven.

In reference to the author's remarks on fuses, he had found that the general rule on the Continent was to use pure silver, which was far more reliable and certain to go at the proper current density. For his part he had given up the use of fuses for large currents except where it was required to disconnect any leads, and preferred to use instead a good maximum automatic cut-out with a carbon break attached. Mr. Vesey Brown.

At his first visit to the Cologne Station in 1891 he found that the authorities were most particular as regards periodicity and pressure, and, in fact, were so successful as to be able to run about two dozen clocks in synchronism with the generating plant, and these clocks were set once a week.

There were many opinions as to the question of using storage batteries, and they had certainly stood the test of time at Dresden and Dusseldorf, but the tendency being all in favour of three-phase generation had to a certain extent displaced the storage battery. There was certainly the point as to constancy of pressure which was more particularly brought to the front when Nernst lamps were used on the circuits, and in his opinion the use of the Nernst lamp required that the pressure should not vary beyond the very narrowest limits from the standard pressure. It seemed a pity that in the town in which they were at the present moment, that the use of the Nernst lamp had to a very great extent been killed by the great variations in pressure to which the distributing system was subjected, and he thought that this might be remedied by the use of storage batteries.

On the Continent the price of supply was as a rule higher than in this country, but this was due to the very lavish manner in which the buildings had been laid out, and as the upkeep was heavy, so the consumer had to pay more for his supply. The Continental proprietors were satisfied with a slightly smaller return on the capital put into the stations, for as a rule, where the stations were not owned by the local authority, they were owned by manufacturing companies, who put a good price on the value of their plant at the commencement. In some cases the tax to be paid by the concessionaire to the local authority before the shareholders received anything was 6 per cent. on the capital employed; in others it was as high as 1d. per unit.

Referring again to the use of storage batteries to steady the pressure, he was informed at Essen that the town authorities imposed a fine for irregularity of pressure and failure to supply, but that up to the present no fines had been imposed in consequence of any failures, etc.

In his opinion the German stations were much better finished than the French and were generally cleaner, though they were both a great deal ahead of this country in this respect.

Mr. C. TURNBULL said he was interested in Mr. Riseley's remarks on cellular switchboards. People were often led to believe that the only fault of this type of board was its high cost, although the board certainly appeared rather inaccessible. He was pleased to hear the criticism of one who had used them. Mr. Turnbull.

With regard to running dynamos without fuses, it was to be observed that an engine's power went off rapidly as soon as it slowed down, and he believed it well worth while—speaking from experience—to have

Mr. Turnbull. dynamos large enough to pull the engine up without damage to the dynamo.

Mr. Snell. Mr. J. F. C. SNELL said he would like Mr. Riseley to tell them whether he found the oil-break switch more in use than the air-break switch. He understood that the Continental practice was to use the horn-switch. He was, however, sufficiently English to have adopted oil switches in connection with his three-phase plant.

It occurred to him that the money spent on buildings—particularly on the engine rooms—on the Continent was very excessive indeed, owing to the fact that they used slow-speed engines which covered a great deal of room. This was, of course, done with an object, the cost of coal being so great that they were obliged to adopt every possible means in their power to reduce the consumption per unit sold. The sub-stations of Berlin struck him particularly as being lavish. The walls in some cases were 36 inches in thickness, and the floors were most heavily made with glazed brick facings. Although land was dear, the fact of putting accumulators on the first floor when they could have been put in the basement seemed waste of money. While he thought that their engine rooms looked better, their boiler-house equipment was wanting when compared with English practice. English central station engineers would be ashamed of the usual Continental boiler house. The arrangement of piping also seemed to be bad. Supposing they had a superheat of 250° at the boilers a good deal must be wasted before reaching the engines, owing to the long pipes employed.

It was interesting to hear the remarks about the single-phase transformers. He found three-core much cheaper than three single-phase to install. None of the previous speakers touched on the question of railways. The Institution had wisely arranged a trip to Italy this year. He hoped the experiments on railway equipment being made in Italy would teach us a great deal and have the effect of awakening our English engineers.

Mr. Clothier Mr. H. W. CLOTHIER said he was not so favourably impressed with the design of Continental switchboards as Mr. Riseley. When he visited stations containing such switchboards he found that the backs were not open for inspection to visitors, and he instanced one place where he learnt that two men had been electrocuted behind the board. He alluded to the comments on British switch-gears, and thought that an unfair comparison had been made. The cellular switch-gears at present in use in this country were designed for pressures of about 5,000 volts and under, whereas the Continental system taken as an ideal was working at 13,500 volts; when the demand for higher pressures arose in this country we should produce designs to excel those seen hitherto by the author. He did not attribute so much importance to the duplication of 'bus-bars which introduced complication and chances of error. He drew attention to an error in one of the diagrams which was a good example of the difficulties due to too much complication; if the draughtsman could so easily err, what was to be expected of the operator?

Mr. Riseley had said that on the boards to be seen on the Continent,

such as that at Paderno, there was "always another way round, *everything* being in *duplicate*, but he (Mr. Clothier) thought that an examination of the diagrams would show that such was not exactly the case. The 'bus-bars were in duplicate, but that was all. He maintained that apart from the complications involved (which were common to any type) there was no difficulty in obtaining by this means "another way round" on the British cellular gear; as a matter of fact he could mention many cases in this country where duplicate and even triplicate 'bus-bars were in use. Mr. Clothier.

He said that flare switches for alternating-current systems were fast dying out, because of the high voltage oscillation set up by the arc. In the light of our experience and the expert opinions of this country and in America, no one would think of installing switches of the same type as those in use on the Valtellina line.

He was entirely in accord with the author in his practical opinion as to dispensing with fuses on the generator circuits, fuses there were more often than not a nuisance; they were wanted on the feeders, and he thought reverse current indicators on each machine circuit were used to advantage.

Speaking of the general design of British switch-gears, he admitted that there was ostensibly much to be done before they could be considered perfect for extra high voltages; but in arriving at finality in design, if that were possible, we should take into account the enviable record of no fatal accidents on the Ferranti cellular switch-gear during all the years it had been extensively used on high-tension supply systems.

Mr. J. H. HOLMES said he had the pleasure of visiting Kander Power Station with some members of the Institution. Mr. Holmes.

The thing that struck him most was the great difficulty they had in regulating and governing their turbines. It seemed impossible to design an automatic governor which would be of any use. When he was there he had noticed the man at the hand-wheel, and he was interested to learn that he was still at it.

Mr. H. L. RISELEY, in reply, said that Mr. Stewart's figures of area of ground per kilowatt installed were very interesting, and he was sorry he could not add to the list. The sole idea of using single-phase transformers was, he was informed, for the convenience of changing over in case a transformer got damaged. *Valtellina Line.*—He presumed that the reason of choosing a periodicity of 15 cycles per second was the wish to mount the motors direct on the axles. The wheels, instead of being 30 inches, were 3·84 feet in diameter on the motor cars, whereas on the locos. they were 55 inches in diameter. The motors were mounted directly on the axles in a very interesting manner. The gear consisted of a very neat parallel-link connection between the driving hollow rotor shaft and the wheels. Each pair of wheels was keyed to the shaft, of which the diameter was 4½ inches less than the inside bore of the hollow shaft, and the link gear compelled the two to rotate accurately together while giving complete freedom to the wheel-shaft to rise and fall with the axle boxes between the horn plates without any vertical motion of the rotor, stator or motor as a whole. Mr. Riseley.

Mr. Riseley The whole weight of the motor was borne on springs; the bearings of the rotor shaft were fixed in the casing of the stator. The wheel was driven by pure torque, that is to say, by two equal and opposite forces producing no reactive resultant pressure in the bearings in which the rotor ran. The whole load, including the weight of the motor, was carried at the axle box.

As regards the primary and secondary motors, each motor car was fitted with two primary and two secondary motors, but on the locos. all four motors were primary, and speed regulation was obtained by using either one, two, or three, or all motors, to suit conditions. On the bogie cars each truck carried two motors, one on each axle. These were used in cascade up to half-speed, and also in slowing down from full-speed to half-speed. In accelerating from half- to full-speed, and in running at full-speed, one of each of the pair of motors was cut out and was running idle. Of course, in cascade-working during the first period of acceleration, the resistance was placed in the rotor circuit of the secondary motor, in the stator of which the voltage did not rise above 300, this being derived from the rotor of the primary motor, which current was drawn off slip-rings. The Controller had only three positions: (1) half-speed; (2) mid position, when the resistance was cut out and the primary rotor circuit was open, and (3) full-speed, for acceleration from half-speed to full-speed.

Mr. Woodhouse mentioned aluminium fuses and seemed to have the idea of making fuse contacts of aluminium strip. Messrs. Parsons & Co. used special blocks for soldering aluminium strip.

As regards the time-limit circuit-breaker he did not see any in operation, though he understood that they were experimenting in Newcastle with them and that they were working fairly satisfactorily.

Regarding the last paragraph of the paper his idea was, supposing you get a number of 100 k.w. generators running in parallel with identical engines of the same rated power. In that case, should any overload occur, all the engines would slow down together, instead of a more powerful engine trying to take all the load and thus upsetting the parallel running of the station. He only offered this as a suggestion.

In reference to Mr. Stoney's remarks, no doubt some of the Continental stations were got up most expensively, especially that of the Schuckert Corporation Station at Vienna. The work of cleaning the station was a big item; in some cases it cost £2 per week to keep the floor clean. He did not remember seeing a station in England kept so clean as the Continental stations.

In regard to the point raised by Mr. Vesey Brown about the cheapness of water-power abroad, the capital expenditure incurred in applying water-power was enormous. In some cases they were using steam plant, as the capital outlay in utilising the water was almost prohibitive, and they found it better to have steam engines.

With reference to sub-stations being well equipped, he did not know that it did not pay to put in all the automatic devices you can. It certainly saved labour.

Turning to Mr. Clothier's remarks: he did not think there was anything in the paper about Ferranti switchboards. There was more than

one type of switchboard called multicellular. There certainly were several points on the Ferranti switchboard which could be improved. Accidents with it were not unknown. It certainly was an advantage to be able to get behind the board, which it was impossible to do with the Ferranti board. He agreed with Mr. Holmes that the governing at Kander was extremely bad. With a large volume of water rushing down under a high pressure, it was evident that the governing could not be very uniform. Mr. Riseley

BIRMINGHAM LOCAL SECTION.

NETWORK TESTS, AND STATION EARTHING.

By A. M. TAYLOR, Member.

(*Paper read before the Section, February 25, 1903.*)

The object of the present paper is, primarily, to describe a new station test, for application under working conditions and on systems where the middle wire is permanently earthed; but as the utility of the said tests—or, indeed, any known test—depends considerably upon the method of earthing adopted, it has seemed desirable to add a few notes on this subject also.

SECTION I.

DESCRIPTIVE OF TEST, AND EXPLANATORY DIAGRAM.

Referring to the simple diagram of circuits, Fig. 3, let E represent part of the earth circuit, and P, M, N the positive, middle, and negative leaks respectively.

D, D are the dynamos or steam balancers at the station. AA is the Board of Trade Recording Ammeter, reading from 0 to 100 amperes, the neutral being earthed through a resistance of 2·3 ohms, as shown.

For the present, consider only the currents P, M, N, and let the leak P be of lower resistance than N, so that the potential of the earth tends towards that of the positive pole.

Consider also, for the moment, that the resistance of the earth is negligible, and hence that the earth potentials at the leak and at the station are the same.

We can represent this state of things by the small diagram on the right-hand top corner of Fig. 1.

Fig. 1 represents, to scale, the changes which take place in the values of N, M, P; and AA, if we can imagine the potential of the earth pulled, by some external means, through every value from extreme positive to extreme negative.

To enable this diagram to be better understood, the author has dissected that part of it which relates to the P and N leaks; and the two triangles, the ordinates of which represent at any moment the actual values of the currents P and N, are shown separately in Fig. 2 (consider only the full lines). The dotted lines of Fig. 2 are intended to help to the better understanding of Fig. 14 (see Appendix, Note 1).

The differential leak is given us by the ordinates drawn between the base line and the line AB, Fig. 1, which for shortness we will call the P–N line: see also Fig. 2. The point at which this line crosses the hori-

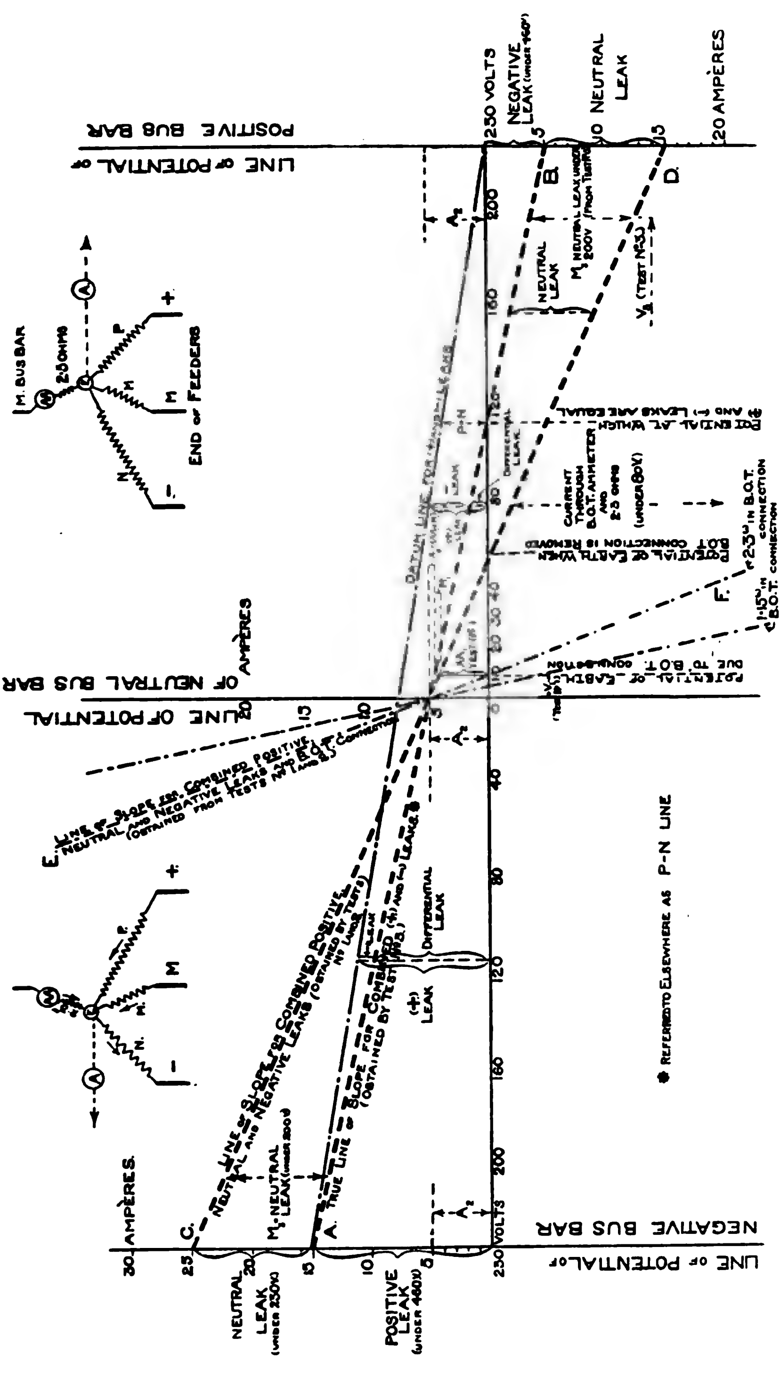


FIG. 1.

In this diagram, Tests Nos. 1 and 2 refer to the "Combined Leak Test," and Test No. 3 refers to the Neutral Leak Test.

zontal gives us the potential of the earth when P = N, there being assumed to be *no* neutral leak.

Next, introduce a neutral leak, indicated by the lengths of the ordinates between AB and CD, and we see the effect in bringing the earth potential nearer to that of the neutral 'bus-bar. The point of crossing of CD with the base line is now at 60 volts.

Again, add a further line EF, representing by the ordinates between it and the line CD the current in the B.O.T. connection (made through

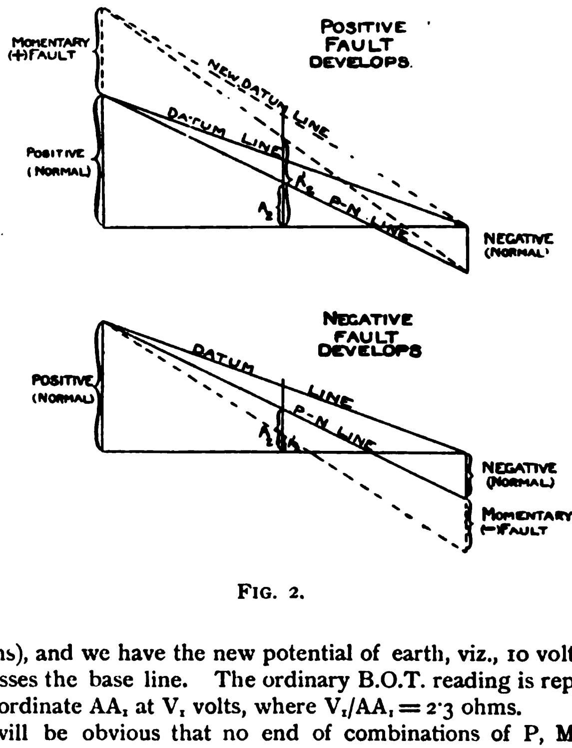


FIG. 2.

2·3 ohms), and we have the new potential of earth, viz., 10 volts, where EF crosses the base line. The ordinary B.O.T. reading is represented by the ordinate AA_1 at V_1 volts, where $V_1/AA_1 = 2{\cdot}3$ ohms.

It will be obvious that no end of combinations of P, M, and N will give the same B.O.T. reading AA_1. Also that from the readings AA_1 and V_1 (or from V_1 alone) we could, if only we knew A_2, the differential leak when V = O, deduce the slopes of the lines EF and CD. The slope of the latter line gives us the *combined* insulation resistance of the three mains; which is :—

$$F = \cot. a = \frac{V_1}{A_2 - \dfrac{V_1}{2{\cdot}3}};$$

where a is the angle which CD makes with the horizontal.

To find the *individual* values of the leaks we must somehow separate out the neutral leak from the others. Obviously, if we could only insert an ammeter in the neutral leak and measure the little ordinate M_1

under V_1 volts, we could deduce the slope of the P–N line; but, unfortunately, this is impracticable, and would be only an approximation in any case, as M_1 is so small.

Referring, however, to Fig. 3, we see that by means of an artificial fault at the station we might put M under any voltage we choose, and measure the increase or diminution of the current supplied from the station to the leak along the neutral feeders. Knowing the current

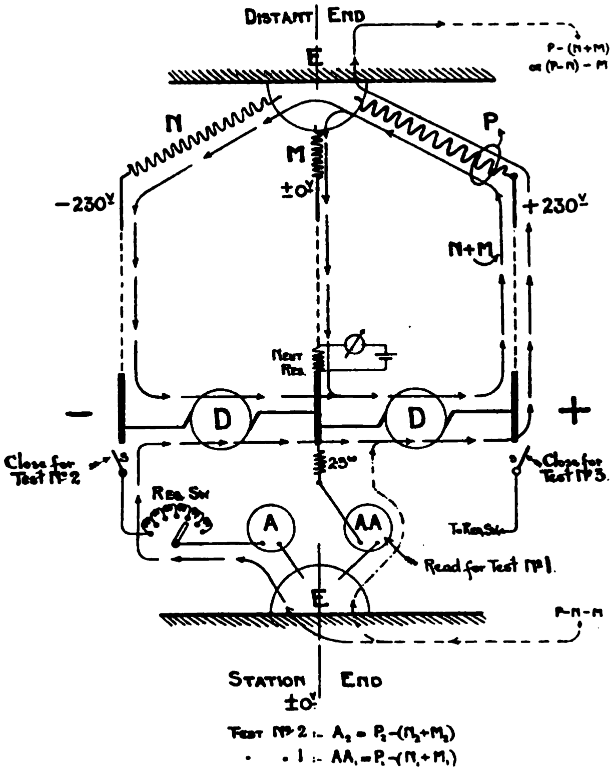


FIG. 3.

produced under V_3 volts, it is sufficiently correct to assume that under V_1 volts we should have V_1/V_3 of the current.

The author has successfully measured the increase or decrease of the neutral current by interposing between the neutral 'bus-bar and the neutral feeders a resistance, consisting of iron plates bolted together, constructed to absorb about a couple of volts, and balancing against this an accumulator cell with an ammeter in its circuit arranged to read zero when the normal out-of-balance current of the station traverses the resistance.

The difference in the reading when the neutral leak is under no

E.M.F. and when it is under V_3 volts enables us to ascertain the current through the neutral leak under V_3 volts, whence we know M_1.

It remains to explain how the reading A_2 is obtained. A reference to Fig. 3 will show how it is picked up by the ammeter A at the station through the switch and adjustable resistance. When $V = O$, then $M = O$, and $A_2 = P-N$.

Where the values of V_1 and A_2 are both so small as to introduce inaccuracy, it may be found desirable to take a reading A_4 at V_4 volts—say 10 volts—to the left of zero (Fig. 1), in addition to the reading A_2 at zero voltage. Then—

$$F = \cot. a \frac{V_4}{A_4 - A_2 - \frac{V_4}{2 \cdot 3}}$$

Fig. 4 shows the testing panel, as arranged by the author. The switch shown at the top, when thrown over to the right-hand side, introduces a central-zero ammeter AA into the B.O.T. circuit, which gives us the normal B.O.T. ammeter reading AA_1 under the voltage V_1 measured on the central-zero voltmeter shown.

The ammeter is unnecessary, since AA_1 can be calculated from V_1, but it saves reference to a table.

The second ammeter A is controlled by the two lower switches, the upper of which puts the free end of the ammeter circuit on to either "outer" 'bus-bar (through a fuse), and the lower on to the neutral 'bus-bar. The other end of the ammeter circuit, which contains an adjustable resistance, is in permanent connection with earth. The circuits are fused for 100 amperes.

To take the reading A_2, all that is necessary is to close the upper of the two lower switches on to the 'bus-bar remote from that towards which the voltmeter reads and adjust the resistance slider till $V = O$. Then on the ammeter A we observe the reading A_2.

To measure the neutral leak, close the top switch on to the left-hand side, thus putting the ammeter AA into the battery local circuit (see Fig. 3), read the ammeter AA, the earth being at about the potential of the middle 'bus-bar, take any suitable proportion of the resistance out of the slider, and close the upper of the two lower switches on to either "outer" stop. The increase or decrease in the reading of the ammeter AA multiplied by a simple ratio—in the case the author has used the ratio is 5/4—gives the neutral leak M_3, and the voltmeter measures the volts V_3 under which it is produced.

For localising a fault to any particular feeder, a 20-way slider is arranged with an ammeter in such a way that the link connecting any one of the neutral feeders to the distributing bar on the neutral feeder panel can be opened, and the ammeter switched into its place.

If the last test be now repeated, the feeder on which the neutral fault exists will give a very pronounced deflection amounting to perhaps 50 or 100 amperes if the fault is a bad one.

Suppose, now, that instead of a neutral fault we had a positive or negative one. Then our test would have shown the neutral 'bus-bar to be sound, and by the slope of our P–N line we should have

known to which side to have looked for the fault. The next step would be to cut some or all the resistance out of the slider, and to close the upper of the two lower switches on to the right-hand stop (for a negative fault), having previously graded the fuse for, say, 100 amperes.

On inspecting the feeder ammeters on the faulty pole, the faulty feeder will be at once seen.

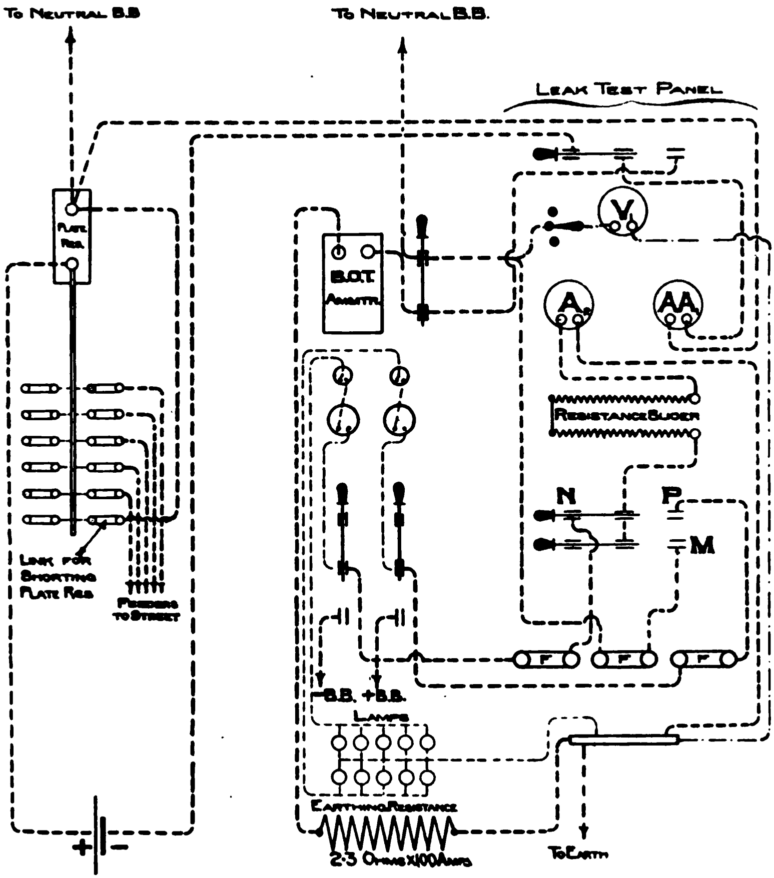


Fig. 4.

SECTION II.

Reasons for a New Test.

The B.O.T. Recording Ammeter, for the reasons already given under Section I., is not, as is well known, of any assistance in gauging the standard of insulation of our mains; though it is, no doubt, of

considerable value as a recorder of any *change* in the state of the insulation (except perhaps in that of the neutral) from day to day. Hence some means of keeping the mains up to a standard is necessary.

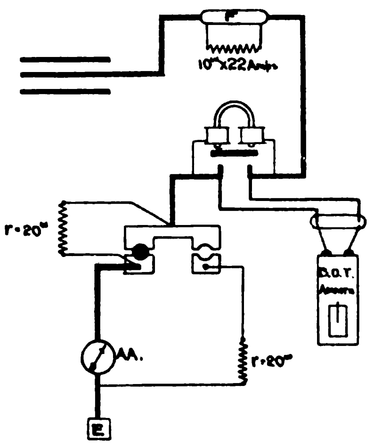
The four tests available were:—(*a*) Fritch's Test; (*b*) Frolich's Test; (*c*) A modification of Frolich's test by, and apparently due to, Mr. F. C. Raphael; (*d*) Mr. Alex. Russell's test.

The first three are described in Mr. Raphael's book on "Faults in E. L. Mains," and they need not therefore be described here. Mr. Russell's test (*d*) is described in the Journal of the Institution, Vol. 30, No. 148.

With reference to these tests, the author would make the following remarks:—

(*a*) Frisch's test is unavailable where the neutral is permanently earthed, through a low resistance or otherwise.

(*b*) Frolich's test is also ruled out of court, because the resistance of the ammeter circuit must be great in comparison with the insulation



COMBINED AMMETER AND EARTHING CONNECTION
RAPHAEL'S TEST C

FIG. 5.

resistance of the network to be measured; that is to say, if we are testing a network in a station supplying, perhaps, 50,000 60-watt lamps, the joint insulation resistance of whose mains might measure, say 20 ohms, we should need to insert an ammeter having in its circuit a resistance of, perhaps, 200 ohms, between the neutral and the earth, instead of the connection required by the Board of Trade.

(*c*) The modification of Frolich's test described by Mr. Raphael, though no doubt more practicable than the others, still seemed to be somewhat unsatisfactory.

In this test the neutral is temporarily connected to earth through an

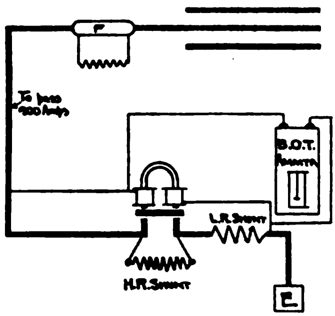
ammeter in series with a resistance about equal to that of the insulation resistance of the network, and this circuit is then shunted by another resistance of equal value.

The resistance to be inserted during the first half of the test would then be, for the case above cited, about 20 ohms.

In the case, however, of a small system, the resistance to be inserted might amount to as much as 50 or even 100 ohms; which would be practically a disconnection from earth.

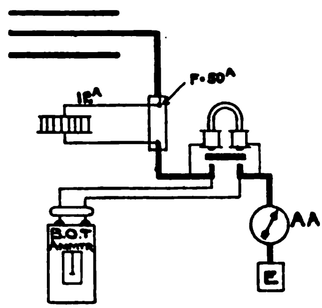
There would seem to be some danger of the two resistances being burnt out, in the event of a bad earth on either "outer" occurring while the test was being made, the connections being as in Fig. 5.

Apart, however, from all questions of safety—for of course the resistances could be constructed to jointly carry 25 amperes under 250



A.T. Abrahams Arrangement

Fig. 6.



Glasgow Arrangement.

Fig. 7.

volts—the reason why this test appeared to the author to be somewhat unsatisfactory was that it only measured the *combined* insulation resistance of the three mains, and not their *individual* resistances.

(*d*) The same objection applied to the test (*d*); with the additional disadvantage that it involved the entire interruption of the B.O.T. connection with earth at the time of making the test.

Now, given that the insulation of the system has gradually fallen below the standard—but with no pronounced leak on either pole—the mere measurement of the joint insulation resistance of the three mains as obtained from test (*c*) does not help us as to which pole we are to look (positive, negative or neutral) for the low state of insulation.

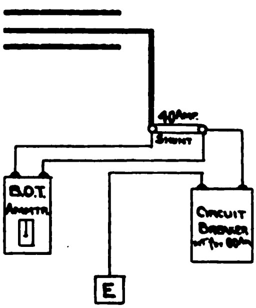
And for the reasons given under Section I. the B.O.T. Ammeter is just as likely to mislead us, as to help us, in looking for the faulty pole; its operation being under similar conditions to those of Raphael's test (*c*).

Suppose, for example, that we had 60 feeders, in all, issuing from the station, viz., 20 positives, 20 neutrals, and 20 negatives, it will

clearly save us a possible 40 unnecessary tests if, to begin with, we know whether the fault is on the positive, negative, or neutral main.

A test panel, to be useful, should therefore fulfil the following functions:—

(1) It must indicate on which pole the leak is developing.
(2) It must enable us to ascertain on which of the feeders (connected to that pole) the fault exists.
(3) It should enable us "to clear"—or, failing this, to localise—the fault by a momentary application thereto of increased pressure; and yet to limit in amount the current which might otherwise be put through the fault.
(4) It should not interfere with the existing B.O.T. connection to earth.



MANCHESTER ARRANGEMENT

FIG. 8.

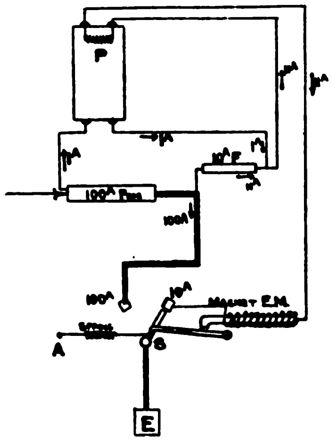


FIG. 9.

The coil P holds the auxiliary 100 amps. pen off paper. A rush of current through the magnets E M and P liberates switch S and auxiliary pen simultaneously. The 10A shunt is shorted by the 100A shunt when switch flies over.

The panel designed by the author, and described earlier in this paper, is intended as an attempt to fulfil the above conditions.

The method of operating the panel is explained under Section I. of the paper.

A further reason for a test which will give us the P and N leaks separately—*i.e.*, the slope of the line AB—is that the B.O.T. Regulations require that, in public supply, the leakage current shall be less than one thousandth part of the supply current.

Now, the supply current is measured by the sum of the positive and negative 'bus-bar outputs; hence the leakage current must be measured in the same way; viz., by the *sum* of P and N. The insulation of the

neutral may be quite low; but the actual leak M through it is, under normal conditions, quite negligible.

Hence, if we obtain the joint insulation resistance of all three mains by any of the tests mentioned, and divide this into 230 volts (to get the actual leak), we shall be misled into thinking that the insulation is below the B.O.T. standard when it is really above it; *nor have we any means of gauging* by how far the state of our mains really comes short of, or exceeds, the B.O.T. requirements.

Most station engineers would like to be assured on this point, and all want *some* standard to work to.

SECTION III.

Relative Efficiency of Different Methods of Earthing.

In considering this subject the two principal things to keep before us are continuity of supply and safety to the consumer. The contingencies that we have to face, as likely to happen outside the station, are :—

(1) Earths on the neutral on consumer's premises.
(2) Earths on either "outer" on ditto.
(3) " " " on the system of mains.
(4) Various combinations of these.

In each case the effect of permanently earthing through a moderate resistance—say 2·3 ohms—will be compared with the effect of a *direct* earth connection, whether made through a fuse of large capacity or otherwise. See Figs. 5, 6, 7, 8, 9.

In Fig. 10 is shown the case of a consumer A whose neutral makes

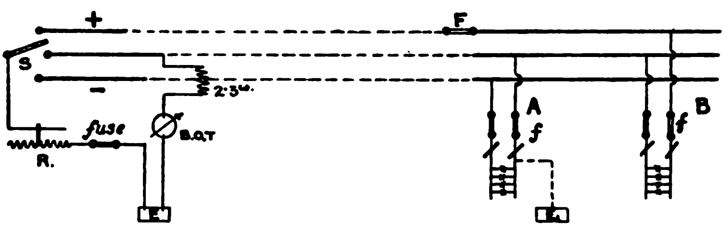


Fig. 10.

an earth connection E somewhere. Here we see that the *partial* earth at the station reduces the risk of a portion of the return current from installations B, C, D, etc., being shunted out of the neutral distributor through A's premises and the fault on his installation, and so blowing the fuse *f* and leaving A cut off from supply—except through the fault—just as the evening load comes on.

In Fig. 11 A's installation is sound, but B has a fault E on his

positive side. In this case the *partial* earth at the station somewhat reduces the chance of B having his fuse *f* blown, and being unable to get a light when he switches on in the evening.

A further advantage of the partial earth is that in case B's installation should be a large one, and its fuse graded too heavy, the distributor

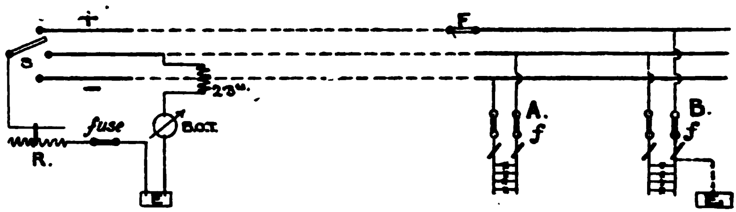


FIG. 11.

fuse F might be saved from being also blown and all consumers on that section being put in the same case as B.

It will also be evident that, by means of the author's test panel, the station engineer can, at any moment, cut out the resistance R at the station and close his switch S; thus blowing B's fuse and locating the fault to a particular feeder.

Also it will be seen that, by means of the fuse on the test panel, the current could be graded and, if found to be so large as to mean the extinction of a number of lights, the blowing of the consumer's fuse *f* could be deferred, at the discretion of the engineer, till daylight.

In Fig. 12 all consumer's installations are sound, but there is a fault

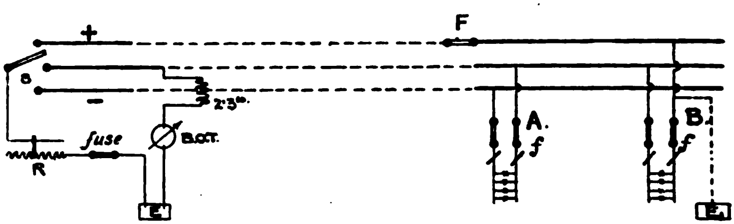


FIG. 12.

E on the service connections or on one of the "outers" of the distributing system.

In this case it is clearly an advantage to have only a partial earth at the station; for if the station "neutral" were earthed *direct*, or through a heavy fuse, there is considerable risk of blowing the distributor fuse F and putting the whole of the consumers on that section in darkness; this, too, for a fault, not on the consumers' premises, but on the mains.

Stating briefly the arguments for, and against, earthing through a resistance in these several cases, we have :—

FIG. 10 :—

(1) Reduced risk of A being cut off from station just as darkness comes on.

FIG. 11 :—

(1) Reduced risk of all consumers on the section being cut off from supply through fault on B's installation.

(2) Reduced risk of B's installation being cut off from supply unnecessarily.

(3) Equal facility for locating from station.

FIG. 12 :—

(1) Reduced risk of plunging all consumers on the section into darkness, through fault on mains alone.

(2) Equal facility for locating from station.

FIGS. 10 and 12 (combination of) :—

(1) Reduced risk of plunging all consumers on the section into darkness.

(2) *Increased* risk of A's lamps being burnt out, through his fuse *f* blowing.

(3) Equal facility for locating from the station.

FIG. 10 and 11 (combination of) :—

(1) Reduced risk of all consumers on the section being cut off from the supply.

(2) Reduced risk of cutting off B from the supply.

(3) *Increased* risk of A's lamps being burnt out (through fault on his own premises).

(4) Equal facility for localising both A and B from the station.

FIGS. 11 and 12 (combination of) :—

(1) Reduced risk of all consumers on the section being put in darkness or cut off from the supply.

(2) Reduced risk of faulty consumer being put in darkness.

(3) Equal facility for localising from station.

FIGS. 10, 11, 12 (combination of) :—

(1) Reduced risk of all consumers on the section being put in darkness or cut off from supply.

(2) Reduced risk of cutting off B from supply.

(3) *Increased* risk of burning up A's lamps.

(4) Equal means of localising A and B and faulty distributor.

Summary of "Pros" and "Cons."

FIGS. 10, 11, 12.—These are the *most likely* cases, requiring the fewest combinations of accidents; and *in every one* of these the conditions are favourable to inserting a resistance permanently at the station between the neutral and earth.

FIGS. 10/12, 10/11, 10/11/12.—These are, in the main, favourable to the change. The faulty consumer is the only sufferer, which is but right.

FIG. 11/12.—This case, again, is all in favour of the change.

There seems, therefore, a distinct preponderance of argument in favour of inserting the resistance.

The above conclusions do not consider the possibility of the fuse, which makes the "dead earth" connection, melting.

It may be argued in favour of having a fuse that, by employing a light fuse to shunt the earthing resistance at the station, the consumer's fuse is saved from blowing (see Figs. 10 and 11), in the case of a light fault.

The answer to this is that, in Fig. 10, the current would not have attained to the dimensions indicated by the blowing of the station fuse had this fuse not *facilitated* its flow by being placed to shunt the resistance; while, in Fig. 11, the fuse might as well have been absent, for it cannot be replaced till the consumer's fuse has blown; and, if the latter do not blow with the former, then ***neither would it have blown*** had there been ***no*** fuse, but only the resistance. In the case of a "dead earth" fault the consumer's fuse is sure to go, anyway.

If, on the other hand, we employ a *heavy* fuse at the station to shunt the resistance we shall have, in the case of a bad fault on consumer's premises (Fig. 11), both current ***and*** pressure available at the fault, or at the consumer's fuse, sufficient to maintain an arc, or do other damage, many times greater than if there had been no station fuse at all.

Further, the fuse involves us in automatic devices, and in two scales, for the B.O.T. Recording Ammeter.

All seems to point, therefore, in favour of having a resistance *without* a fuse to shunt it.

Current-Carrying Capacity of Earthing Resistance.

It will be noted that the current which the resistance is designed to pass (under 230 volts) should bear a definite relation to the current at which the smaller sizes of distributor fuse are set to blow.

If primary importance is to be given to the prevention of the blowing of distributor fuses (due to "earths" in distributors, or on premises of large consumers), then the resistance must not allow a current to pass sufficient to blow the smallest distributor fuse—or, if the section be fused from both ends, the pair of fuses.

On the other hand, if the earth potential is to be kept, at all costs, as near to the neutral potential as possible, the resistance must be as low and have as large a current-carrying capacity as possible; but in this case we shall have distributor fuses—perhaps even feeder fuses—blowing on the smallest provocation.

Taking into consideration the fact that, with the panel devised by the author, the engineer can blow any distributor fuse (on a faulty distributor) at discretion, the safest course would appear to be to design the earthing resistance so as to *save* the distributor fuse or fuses, and to connect an alarm bell between the neutral 'bus-bar and earth, to ring with, say, 50 volts. The engineer can then close the switch S, Fig. 10, when the bell rings, first through a fuse insufficient to blow the distributor fuses; and then, if this still fails to clear the fault, through a heavier one; or if the voltage is not much over 50, he may elect to risk leaving it alone.

Earthing the Neutral at Feeding Points only.

The argument for earthing at this part of the system is, the author believes, principally that currents from faults on consumers' premises would form *local* circuits from the faults to the nearest earth connection, instead of, as now, having to traverse the whole town in order to get to the generating station. There would thus, it is argued, be less probability of interference with telephone circuits, gas and water pipes, etc.

The argument appears to be intended to apply only where there is a *completely* earthed neutral over the whole distributing system (the

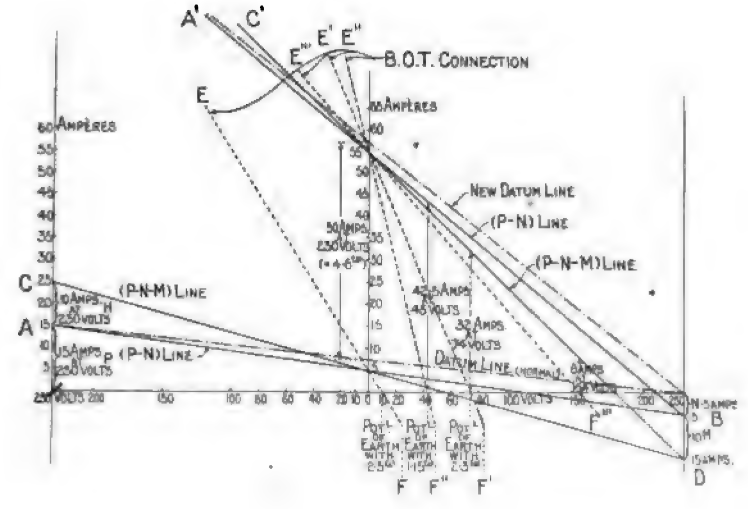


FIG. 13.

author shows later that it does not altogether hold here either). For if there be any resistance inserted—the diagram (Fig. 13) shows that a comparatively small "outer" leak will divert the potential of the earth by, say, 100 volts from that of the neutral.

The result of this will be that not only will the local earth plate of the particular section of distributing system be thus called into operation, but the whole of the other earth connections as well, thus setting up a network of earth currents all over the city.

Fig. 14 shows this condition of things, and the connections at the station for the author's test. It also suggests the undesirability, where there are substations in a town, of interlinking the networks supplied by these substations with that supplied by the main station, or with one another.

Risks with the Neutral Completely Earthed.

If, to avoid the difficulty described above, we cut down the resistance materially at the earthing points, we come to what is practically a *direct* earthing of the neutral at each distributing centre. It is true that we have now practically eliminated the chance of a consumer's fuse blowing under the conditions of Fig. 10; but have we not jumped out of the frying-pan into the fire? For it is impossible to conceive that the whole of the feeding centres of the town will always, as regards their neutrals, be at the same potential above or below the earth *except* by the flow of large earth currents from one centre to another.

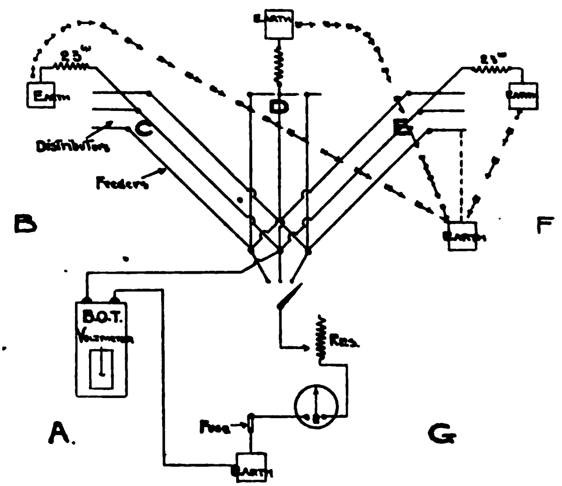


FIG. 14.

We shall have *invited* this by reducing the resistance so low between neutral and earth at the various centres; for the neutral feeders all come off a common connection at the generating station, and the "drops" in the feeders cannot conceivably be all equal.

The argument still holds to some extent, even though the neutrals be earthed continuously throughout the distributing system.

Again, all the disadvantages enumerated earlier against the reduction of the earthing resistance at the station still hold in their most aggravated form.

Testing with Neutral Completely Earthed.

It looks as if any attempt to measure the insulation resistance of the outers under such conditions would be unsuccessful, without disconnecting sections one by one.

The importance of being able to measure the insulation of, and to

localise faults on, each pole in turn, by a momentary earthing of one of the others, can hardly be over-rated.

Hence the use of a bare neutral distributor will, on this score alone, be distasteful to the average station engineer.

Again, since the state of the insulation of the "outers" is unknown, there may be considerable leaks developing all over the system, with the insulation gradually falling; but nothing will be known of it (the B.O.T. Ammeter has been "scrapped") till it becomes sufficiently accentuated *in one spot* to cause a fuse to blow.

Thus the insulation will get lower and lower, with no means of checking, or putting suspected parts under sufficient pressure to break down the fault.

A system which keeps the "outers" *up to a definite standard* seems to the author the only possible safe one, and this is not to be obtained where the neutral is completely earthed; nor where the earth connection, if *direct* to earth, cannot readily be removed by the station engineer for purposes of testing.

Conclusion.

It seems, on the whole, as though the most satisfactory all-round method were to earth permanently through a resistance and at the station.

When the connection is made through a fuse, without other resistance permanently in circuit, as is now rather general, it would seem that, the moment the fuse goes, all control of the rise of potential of the earth is taken out of the engineer's hand; and another fuse cannot easily be inserted unless the B.O.T. connection be entirely opened, when the voltage of the earth might be practically that of either of the "outers."

In conclusion the author hopes that this effort to draw discussion on a subject which seems to him to have been insufficiently ventilated, may not be considered a meddlesome interference with things which have long been settled.

APPENDIX.

NOTE I.—CHANGE OF POTENTIAL OF EARTH DUE TO FAULT ON EITHER "OUTER" MAIN.

Fig. 13 has been prepared to show the relation between :—(1) the current flowing through a fault on either "outer"; (2) the current in the B.O.T. Recorder; and (3) the rise of potential of the earth itself as compared with neutral B/B potential.

The fault corresponds with a momentary demand of about 34 amperes on the positive side of the station (or 39 amps. if we *include* the normal positive leak), the actual current through the fault being given by the ordinate enclosed between the new "datum line" and the old, at the proper potential (viz., 74 volts).

The lines E′ F′, E″ F″, E‴ F‴, correspond respectively with 2·3 1·15, and 20 ohms in the B.O.T. connection; and the potentials of earth are given by their intersections with the base line.

The normal position of the P—N line is shown by AB and the temporary position, due to the fault, by A′B.

The potential of earth, due to the fault, changes by 64· volts when 2·3 ohms are in the B.O.T. connection and by 30· volts when 1·15 ohms are employed.

If 20 ohms be employed in the earth connection—a not unusual value—the rise of potential, due to the fault, is no less than 145–150 volts.

The currents traversing the B.O.T. ammeter are also clearly shown.

In Fig. 11 B's fuse *f* would carry, or blow with, the 34 amperes, there being 2·3 ohms in the station earth connection.

Mr. Raphael. Mr. F. CHARLES RAPHAEL (*communicated*): Mr. Taylor has been kind enough to mention in his paper a method of testing the insulation resistance of networks during working which I suggested six or seven years ago. At that time I was preparing the book to which he alludes in his paper, and I made inquiries to ascertain what periodic tests were being made of the insulation resistance of networks. I was then rather in the position of a specialist, being usually only called in to locate the trouble and operate when the case had reached a critical point, and I was anxious to learn from the family practitioners how they diagnosed the disease of mains breakdown in its incipient stages. To my surprise I ascertained that the testing of networks for insulation was comparatively rare. The two or three engineers who did test them employed Frisch's method of connecting a voltmeter or ammeter between each main and earth when, as is well known, the insulation resistance of the whole network is calculable from any two of the readings.

Just then the 2 × 220 volt three-wire network with the neutral conductor earthed at the station was coming into vogue, and I therefore suggested the middle-wire ammeter method of measuring the insulation of the network mentioned by Mr. Taylor. Perhaps I may be allowed to explain here what this test is, as I am bound to confess that I did not recognise Mr. Taylor's Fig. 5 until I read in the foot-line that it was "Raphael's test," and it therefore may not have been clear to others either. An ammeter (either having a long range or appropriate shunts) is connected between the middle wire and earth through a resistance which is normally short-circuited. To make the test, the short circuit is removed, and a reading d_1 is taken. Then the ammeter and resistance is shunted with a resistance equal to the series resistance *plus* the resistance of the ammeter, and a second reading d_2 is taken. If r is the resistance of the ammeter *plus* its series resistance, the insulation resistance of the network is $\frac{d_1 - d_2}{2\,d_2 - d_1}\,r$. This method would appear to be applicable without the second ammeter, which Mr. Taylor designates "Board of Trade" ammeter in his Fig. 5. The resistance r would have to be of the same order as the insulation resistance of the network, and thus it must be normally short-circuited, as the function

of the earth on the middle wire is not fulfilled unless the resistance of this earth connection is a fraction of the fault resistance of the other mains. Mr. Raphael

I do not know whether this suggestion has been acted on to any great extent. I believe not, and that, when tests are taken—which is rare,—the earth on the middle wire is removed for a few moments, and Frisch's test is made. It may be noted that it is only necessary, in making Frisch's test, to earth two (any two) of the three wires through an ammeter or voltmeter, for the insulation resistance—as well as the reading which would have been obtained from the third wire—is calculable from the two readings.

It appears to me that, whatever method is employed for measuring the combined insulation resistance, this insulation resistance compared with the middle-wire ammeter reading will indicate on what main a fault has developed. Normally, for instance, the current through the middle-wire ammeter is *from* the middle wire *to* earth, indicating that the insulation of the negative main is worse than that of the positive main. Suppose this to be the case, and that the test of the combined insulation resistance one day gives a lower result than usual: if this is accompanied by an increase in the middle-wire ammeter reading, it indicates a decrease in the insulation of the negative. If, on the other hand, the middle-wire ammeter reading is below the normal, in spite of the decrease in insulation, the fault will be on the positive or neutral, the effect of a fault in the neutral wire upon the ammeter deflection being relatively less than a fault in the positive.

Coming to Mr. Taylor's suggestion, I must own that, with the limited time at my disposal, I have been unable to understand entirely the method he proposes. Has he checked his graphical explanation by an analytical proof, or by employing Mr. Alexander Russell's ingenious load diagrams? Perhaps in his reply to the discussion he will be good enough to make his method a little clearer. If he is really measuring the current leaking away from each main separately, his test should be most useful; but, if his method is a rough approximation only, and is influenced by the load on the network, a simple method such as Frisch's or "Raphael's" is preferable in my opinion. A momentary disconnection of the earth on the middle wire for the former method is not likely to be attended with serious consequences, and a momentary increase in the resistance in the middle-wire earth for the purposes of the latter method would surely be quite harmless.

Mr. Taylor has done good service in calling attention to the necessity of testing electric light networks, and I trust that his paper will not lead to the opinion that such tests are complicated or difficult to carry out. The contrary is the case; testing the insulation resistance of a network during working is one of the simplest electrical measurements.

Mr. ALEXANDER RUSSELL (*communicated*): I regret that I shall be unable to be present at the meeting, especially as there are one or two points in the paper which I fail to grasp. The diagrams would be so much more easily understood from Mr. Taylor's explanations. The absence of formulæ also makes it difficult to follow the methods, and makes it almost impossible to gauge their accuracy. I have attempted Mr. Russell.

Mr. Russell. to supply some of these formulæ with, however, only partial success. My attempts will enable Mr. Taylor to see whether I have understood him or not, and may probably be of assistance to others. The author's solution is deserving of the most careful study by station engineers.

In my paper published in the *Journal* and referred to by Mr. Taylor it is shown that if we make an artificial leak to earth from any of the mains, and if $V - V'$ be the simultaneous change in the P.D. between each of the mains and earth, then

$$\frac{V - V'}{C} = F,$$

where C is the current in the leak, and F is what is called the insulation resistance of the network. For various reasons the value of F is always altering slightly, so that a very accurate measurement of it is not wanted.

Now, since the earth connection of the middle is an artificial leak, therefore

$$\frac{V_2 - V'_2}{C} = F.$$

Where V_2 is the P.D. between the middle and earth when the earth connection is removed, V'_2 is the P.D. between the same points with the earth connection in its place, and C is the current in the earth connection. If we plot a curve with V'_2 for abscissa and C for ordinate, then we get the line C D in Fig. 1. If we alter the resistance of the earth connection, then

$$\frac{V_2 - V''_2}{C'} = F,$$

and hence

$$F = \frac{V'_2 - V''_2}{C' - C}.$$

The drawback to this method of measuring F is that $V'_2 - V''_2$ is only about 10 volts, and it is not a steady voltage. Also, since F is about 10 ohms, $C' - C$ is about an ampere, and could not be determined with any great accuracy. I should certainly not use this method.

Another method—and this, I think, is the method Mr. Taylor uses—is to make an artificial leak on either of the outers. In this case we have

$$\frac{V_2 - V'_2}{C} = \frac{F R}{F + R},$$

where C is the current in the leak and R is the resistance of the earth connection. This is the equation to the line E F in Diagram 1. Since we can make $V_2 - V'_2$ equal to 200 volts or so, we can determine $\frac{F R}{F + R}$ easily to within two or three per cent. Hence, unless F is large compared with R, we can determine it approximately when we know R.

It seems to me that it is unnecessary to worry ourselves about how to measure the insulation resistance with the earth connection in its position, seeing that it is perfectly simple to open this connection during

the few seconds required to measure F. In the network considered the potential of the negative outer would then be — 280 volts, and this is not very alarming. The author seems to have had the neutral at 200 volts, and therefore the P.D. between the negative outer and earth must have been — 430 volts during his test. Mr. Russell.

I hope Mr. Taylor will explain a little more fully the principle of the method he uses for measuring the leakage current in the middle main, as if it can be done accurately, or even if it can only be done roughly, it represents a very considerable advance in our knowledge. It is easy to devise theoretical methods of doing this by keeping the two sides of the three-wire system at different potentials during the test, but the only methods known to the writer are too elaborate for practice.

The author seems to put a resistance in series with the neutral leaks, but as this resistance would be traversed also by the consumers' out-of-balance load, and as its resistance is very small compared to the resultant leak on the middle main, I fail to see how he manages to separate out the middle leak.

In most three-wire networks, when we alter the potentials of the mains, the fault resistances of the three mains vary, although the insulation resistance F of the mains remains the same. Hence we are not justified in assuming that the resultant leakage current from a main and the wires connected with it varies as its voltage from earth.

Since the distributing mains are underground and cannot be inspected, it is of vital importance to the working of the station that they should be subjected to periodical electrical tests. Mr. Taylor's testing panel is therefore a step in the right direction, and is deserving of the highest praise. Even if he has not succeeded in separating out the three leaks, we can determine the insulation resistance of a network rapidly by its means, and an inspection of these records will be of far greater value than an inspection of the record of the leakage current in the earth connection.

Mr. A. P. Trotter said they were greatly indebted to Mr. Taylor for the paper, and also to those members who had asked him to give further explanation; for he had read the paper through twice, and he had been greatly puzzled by Fig. 1; but a great deal of it was made more clear by the explanation of the diagrams placed before them that evening, and the way in which Mr. Taylor described how the potential of the earth was pulled over in one direction or another by the ammeter was very interesting. He only wished he could follow how the ordinary out-of-balance current affected this; he did not quite see how that would be. He should understand it in a perfectly well-balanced circuit—however, he would not go into details on that matter. He was puzzled very much over what was the meaning of the height of the ordinate (A_2) in Fig. 1. Under the normal circumstances, when there was no leak at all, Mr. Taylor began with the ordinate and a slope to the datum line. There was a normal diagram with no leaks at all, and then there began to be slopes representing the leaks. He was glad Mr. Taylor had called attention to Mr. Russell's paper in Vol. 30 of the Institution *Journal*; it was an extremely interesting one, and most Mr. Trotter.

Mr. Trotter. unfortunately was not in the index of that volume. It was a paper attached to No. 148 of that volume. Mr. Russell dealt with the problem like a steelyard. He took the centre of gravity as the neutral point at which, if you made a connection, there would be no leak; and he took the faults as loads on the bar, and treated them from the point of view of moment. He (Mr. Trotter) thought Mr. Taylor's method of diagrams, *when fully explained*, might be a still better way. Some people were more fond of algebra; but he was one of those who preferred a diagram when he could understand it. Mr. Taylor described the various ways in which the stations were earthed. He (Mr. Trotter) had to go into a good many stations and he very often asked the engineers how they earthed their middle wire, because he wanted to know; though it was not part of his duty because, fortunately, there were no Board of Trade regulations describing how it should be done. The general principle, he believed, of connecting the middle wire was to prevent any consumer getting more than a 250-volt shock. He believed that was the object, because the regulations began by saying he must be liable to no more. Of course, if there was a three-wire network, and there was a leak on the negative, up went the positive, and a man might get a shock off it. There was no harm in opening the earth connection at the proper time for a few seconds, but there was the stress you put on the wiring; a bigger stress was put upon the wiring than it was usually intended for. The use of the ammeter was not by any means universal. He came across works the other day in charge of a young engineer where there was no ammeter, no fuse, no switch—but the earth dead connected up. He hoped it might be so for long, but he fancied the engineer had something to learn, and he would no doubt have recourse to one of these devices. Some time ago he (Mr. Trotter) had to do with a very serious gas explosion. The gas company declared that the electric mains had exploded, and laid it all down to them, and he had to investigate it. He went to the works and asked how their middle wire was connected. It was connected to a recording ammeter; they showed the record for the day with the line dead straight and at zero. He asked the gas company if they had any instrument that would show their leaks, and they had not got one. One of the first recording ammeters he saw was at Glasgow. Mr. Chamen had found it most useful in tracing the leaks. He imagined that the use of that device would become very much more common than it was now. He once discussed what there should be in addition, at a meeting of the Municipal Engineers, that being, he believed, the first occasion on which the subject had ever been dealt with, though it was a most important subject. It seemed that there should be a resistance, otherwise there would be a dead short; such a resistance should be provided that at all events the plant could handle the current; some engineers suggested 10 or 20 ohms resistance. This was too much, and would defeat the object of earthing. He thought that the normal condition should be a dead earth on the middle wire, and a circuit-breaker set to open with a heavy current, throwing in a resistance and giving an alarm signal, and perhaps altering the sensitiveness of the recording ammeter,

Then came the question, if there were a heavy leak on the negative, how much would the positive go up? As Mr. Taylor had said, putting that resistance in would hold the middle wire down, and Mr. Russell went so far as to say that he would like to put the resistance in the sounder main to hold it down. He treated it from the point of view of a balance; if a heavy leak came on and pulled it down, he would like to put an artificial leak on the other end to hold that down; but a smaller leak at a greater leverage. He said it would consume so many kilowatts, and those might be useful in the station. But he (Mr. Trotter) thought no engineer had ever driven his pump, off that source of energy. He asked the people who had suggested 10 or 20 ohms in the earth circuit what they would do if there were a bad fault. Would not the sounder main go up above 250 volts? Mr. Trotter.

Mr. Russell's paper enabled one to calculate with some trouble, and he hoped that Mr. Taylor's paper would, when carefully considered, enable one to calculate with more ease. What was the maximum resistance that could be put to earth so that the sounder mains should not rise more than 250 volts above earth when a heavy leak occurred upon the other one? One railway company objected to some people putting their middle wire to earth at all; they said they would disturb their signals very much, but they added that if the people in question would put 1,000 ohms between there and earth, they would not raise any further objection. He wished to raise a little protest about any fuses or switches at all in middle wires. These troubles, it seemed to him, would be got over by considering the middle wire was at earth potential. The only way in which it could differ from earth potential was by a few volts owing the drop due to the current itself. If a leak occurred in a consumer's house, as was shown in one of the diagrams, what harm could happen as long as there was no switch and no fuse between that leak and the middle wire?

Mr. TAYLOR: Are you alluding only to fuses on consumers' premises or in the distributing main as well? Mr. Taylor.

Mr. TROTTER: Anywhere. Mr. Trotter.

Mr. TAYLOR: Because no fuses are shown on the neutral distributing main. Mr. Taylor.

Mr. TROTTER said it was rather startling to some people, but he believed Major Cardew held from the first, and he knew a good many engineers also held, that there should be no fuses and switches at all on any wire connected with the middle wire; let it all be considered to be an earth potential. Although he regarded that as earth potential, he was one of those who held very strongly that the middle wire should be earthed at one point only and insulated at all other points, as the Board of Trade asked. There had been a good deal of talk lately over the German system of abandoning insulation altogether on the middle wire, and having it earthed all over the place, but Mr. Taylor showed one or two reasons why that would be undesirable. Under such a system it would be impossible to make any tests at all; there would not even be the recording ammeter at the station to tell what was going on. He had hardly found any engineers who wanted that system except they wanted to pick up village lighting on the cheap. Mr. Trotter.

Mr. Trotter.

It was fair to say that they claimed that leaks would develop rapidly into shorts, and that this result would tend to the happiness of the greatest number; but he was not convinced. But they were in the habit, he believed, of putting in insulation in excess of the work it had got to do. Why insulate for 250 volts? It was never going to get that; let them insulate it reasonably. As Mr. Taylor had said, if they set up a network of earth currents all over the city, and could not get at them to test them, it would be liable to give rise to very serious difficulties. It was quite a common practice to open the earth connection for making a test, but if Mr. Taylor's paper would enable engineers to make their tests without opening the earth connection, he thought a very great step in advance would have been made.

Mr. Duesbury.

Mr. T. DUESBURY said that he could thoroughly endorse Mr. Taylor's reasons for a new test. He regarded the disconnection of the middle wire from earth for testing purposes as inadvisable, as it threw a great strain on the wiring. The knowledge that in the test described by Mr. Raphael the combined insulation only could be obtained, had, despite the regulations of the Board of Trade on the point, led most engineers to trust more or less in Providence, which trust was apt to be occasionally badly shaken. He could strongly endorse Mr. Taylor's views as to the middle wire permanently earthed through a low resistance being absolutely the best method of earthing, as he had experience of two other methods—earthed direct without any fuse, and earthed through a low resistance short-circuited by a fuse. It was unnecessary to consider the first, as the foolishness was apparent. The second method had one very weak point, that the advantages of low resistance were only utilised in the case of a fault sufficiently bad to blow the fuse, and consequently cut in the resistance. For some time, he ran at Sutton Coldfield with the middle wire directly earthed, but during the last nine months he had inserted between the middle wire and earth connection a resistance of 4 ohms, able to carry 60 amperes continuously, and he could confidently say that the number of cases of consumers' main fuses blowing had decreased by at least 50 per cent. He could also speak of the value of the recording ammeter in the way of locating small faults. On account of the big earth currents which must flow between feeding-points, he regarded the earthing of the network at feeding-points as altogether wrong, and he thought, if anything, he should much prefer the middle wire earthed throughout its whole length. Although quite foreign to the subject under discussion, he should like to remark that in some cases too little attention was frequently paid to the method of making the earth connection itself, and consequently the earth plate had an appreciable potential difference to the earth surrounding it. He recently heard of a case where the engineer connected the middle wire to the exhaust-pipe system, and seemed quite pained when he had to buy new boiler blow-down cocks within twelve months.

Mr. Groves.

Mr. W. E. GROVES (*communicated*): While fully appreciating the importance of Mr. Taylor's paper, and particularly of the analytical diagram, Fig. 1, I cannot regard the test as it stands as likely to be of any

great service for frequent station use—say, twice daily in the morning, and at top load. Mr. Groves.

It should be possible for a "switchboard attendant" or his equivalent to report the state of the insulation when required to do so, particularly when there are several stations or substations, and I am afraid if Mr. Taylor's test were used in this way it would too often produce unsatisfactory results. Of course the idea of discriminating between the fault resistances of the three poles is most attractive, but facts are of greater importance than figures.

Mr. Alexander Russell's paper referred to by Mr. Taylor is a most valuable one, and the simple insulation test described in it very strongly commends itself to me. It involves the opening of the earthing switch momentarily, and this switch could be controlled by a spring to prevent its being left opened accidentally.

Normally, the D.P. between neutral and earth, if the switch were opened would be less than that involved by Test No. 3. The last-named test also involves the flashing about of considerable currents and voltages to the detriment of instruments and switches; it should be therefore only resorted to when the insulation has fallen too low. Referring to Mr. Russell's simple formula $F = \frac{V_2 - V'_2}{c}$, $\frac{V'_2}{c}$ is the resistance of the coil in series with the B.O.T. instrument; the test therefore resolves itself into a reading of ammeter in the earth connection and a momentary breaking of earthing switch to read V_2.

It is an easy mental operation to divide the latter by the former and diminish it by R. If F is high and R low (say 2 or 3 ohms), the latter may be neglected so that F is simply $\frac{V_2}{c}$. If F is above the selected standard the test is completed. If the test shows that F has fallen too low, the faulty or the *most* faulty pole will usually be indicated by voltmeter. If there are faults on both sides the removal of the greater reveals the less.

Occasionally we may be confronted with the voltmeter refusing to move appreciably when the earthing switch is broken, which would mean that the P and N leaks were exactly balanced (a condition of things rarely existing in practice) or that M is faulty. In this case having the voltmeter in front of us reading near zero there is no harm in leaving the earthing switch open, as it can be closed immediately the volts rise. This would avoid heavy current through the B.O.T. instrument while you perform what is a rough Test No. 3. If the neutral is sound the flashing will not effect the neutral ammeter, if otherwise, a "kick" will result. If outers are at fault the ammeter on the pole opposite to that flashed to earth will "kick." With suitable arrangements the switchboard attendant can easily read $\frac{V_2}{c}$, and if he reports that the insulation is down, the analysis of F can be undertaken by the mains superintendent.

Obviously the essential difference between Mr. Taylor's and Mr. Russell's tests is that the former reads A_2 (vide Fig. 1) and the latter volts between neutral and earth when earthing switch is open.

Mr. Groves. Mr. Taylor does not read the cotangent the angle C D makes with the horizontal directly, and A A_1 and A_2 must be very accurately read, but neither does he open the earthing switch. Mr. Russell reads this cotangent more directly as the expense of opening the earthing switch. I do not think any apology for opening the earthing switch is necessary if the insulation resistance can be more readily ascertained by the operation, particularly as the switch need only be opened for a moment.

The testing panel as designed by Mr. Taylor lends itself admirably to the performance of Mr. Russell's test as well as that devised by Mr. Taylor. It also permits the modification of the test suggested above being very readily carried out.

As a record of change and occasionally indicating to what kind of apparatus a fault is due, the B.O.T. recording ammeter is valuable, but the fallacy of relying on it to indicate the state of the insulation does not require emphasis.

Concerning the method of earthing. There should be no sentimental objection to blowing a consumer's fuse if a fault should develop in his installation.

The earthing resistance should be sufficiently low to allow currents to pass which will blow, with perhaps a few exceptions, the largest consumer's fuse should his insulation break down.

Any fuse in the network should be sufficiently heavy to avoid risk of a faulty consumer putting his neighbours in darkness.

Earthing without control would render efficient supply impossible and bring the business into disrepute. It would be small satisfaction to consumers to be told that supply could not be given because of a fault for which they may be in no sense responsible. Consumers would often be at the mercy of the industrious navvy who may have inadvertently driven into the supply mains.

Mr. Ashlin. Mr. F. J. W. ASHLIN (*communicated*): The test for obtaining actual readings of neutral leakage on a three-wire system seems a distinct step in advance of what could be previously determined by known methods. Such a test panel should be a welcome adjunct to any central station, giving a station engineer a ready means of knowing the state of the insulation of the supply system at any time.

From practical experience of the use of the panel as described I think that readings taken when a moderate fault develops, *followed up by actual search to locate the leakage*, will in many cases save the ultimate annoyance of possible heavy short-circuits, sometimes blowing the feeder fuses at the station end during time of heavy demand.

I would point out that the test panel as described would not appear to be so necessary when a leak develops on any feeder, amounting to a "dead earth." Assuming a differential reading B.O.T. recording-ammeter is used, this will at once show by the deflection on which side the leakage is taking place, and the result can generally be seen at once on the feeder ammeter on the switchboard in the extra load recorded.

If a fault of this magnitude comes on, say, before or during heavy load on the station, the earthing resistance (as advocated by Mr. Taylor) must carry its full current the whole time until the fault can be located

or cut out. At such a time it would be an advantage to be able to insert other resistance in parallel with the station earthing resistance. Mr. Ashlin

If, by any chance, the earthing resistance is subjected to double the voltage for which it was designed, say, 400 to 500 volts, through, say, a complication in a street box, the consequences to the resistance itself would be rather disastrous!

As regards the instruments—ammeters and voltmeters—used on the test panel, these require to be particularly accurate and should be frequently calibrated, as the effect of "pulling the potential hard over" is rather severe on the instrument. Any error would apparently be multiplied considerably if referred to the lines of Fig. 1, and would give misleading results as to the actual amount of leakage.

Instead of an accumulator cell and ammeter for the neutral test (as the cell requires attention by a battery attendant), would not an ordinary small 2-volt cell be sufficient, with a voltmeter to measure the drop of potential?

Mr. A. M. TAYLOR (*in reply*): Mr. Alex Russell describes his own test, which I quite recognise as a most useful and simple one. It is one which the consideration of Fig. 1 led me to several months ago, before I had unearthed Mr. Russell's paper; but having set myself the problem of devising a test which should not interfere with the earth connection, I (perhaps wrongly) rejected it as a solution of the question. Mr. Taylor.

Mr. Russell suggests that my method is to make an artificial leak on one outer and measure the current in it. That is so, as regards the *first* part of my test, which only carries us as far as the obtaining of the joint insulation resistance of the three mains, indicated by the slope of the line (C D) in the diagram, Fig. 1.

The second part of the test is quite distinct from this, and consists of what we may call a "discriminating" test. By means of the artificial leak we can cause the potential of the earth to travel away from that of the neutral 'bus-bar to any desired extent—say 200 volts. This puts the neutral leak of the system under 200 volts, and if the insulation resistance of the neutral system were 10 ohms then 20 amperes would flow. This would increase or diminish the algebraic sum of the current in the neutral feeders by that amount.

Suppose that, prior to making the change in the earth potential, and immediately after making the first part of the test (which left the earth potential *at* that of the neutral 'bus-bar), the out-of-balance current of the station is found to be, say, 50 amperes, then, on closing the artificial leak so as to put 200 volts on the neutral leak, the momentary increase in the out-of-balance current will be 20 amperes, and on opening the artificial leak again it will diminish to its original value of 50 amperes.

We should thus know that the neutral leak alone had a resistance of 10 ohms; and, having previously measured the joint insulation resistance of the three leaks, it is the easiest thing to deduce the combined insulation resistance of the positive and negative leaks *without* the neutral leak.

Mr. Russell's question as to whether the current through the leaks really obeys Ohm's Law or not is a most interesting one; because, if it

Mr. Taylor. did not, it seems that all tests hitherto considered are valueless. I am glad to be able to assure Mr. Russell that it does. On a particular town's system, applying the "discriminating" test, I found the neutral leak to be :—

15	amperes	under	200 volts
7½	"	"	100 "
3	"	"	50 "

indicating—especially as the last figure could not be measured very exactly—a very good agreement with Ohm's Law.

Mr. F. C. Raphael suggests that by means of his test he can really discriminate between the leaks. The method he suggests is to measure the joint insulation resistance (F) of the three leaks, and compare this with the B.O.T. Ammeter reading.

In any case we only can by this method measure the *change* in the resistance of any one main—not its actual value. If things are to be kept up to a standard—the B.O.T. standard—we must be able to measure the actual value.

Mr. Raphael questions the correctness of the diagram Fig. 1, but I think the fact that the equations, both for Mr. Russell's test and for his own, can be deduced from it are a proof of its accuracy. Mr. Russell has apparently accepted it, for he has pointed out that the joint insulation resistance (F) as measured by his test gives the slope of the line (C D) in my diagram.

In reply to Mr. Raphael's inquiry whether the discriminating test is not affected by the load on the network, I may say that in the reply to Mr. Ashlin's remarks I have gone into this question somewhat more fully than in the paper itself.

Mr. A. P. Trotter asks the very pertinent question : "If we have a heavy leak on the negative, by how much will the positive 'bus-bar potential rise above that of the earth?" I submit that Fig. 1 fully indicates the principles on which we can determine this, and in Fig. 24 (shown among the lantern slides, and now incorporated in the paper) the actual rise of potential of the earth towards that of the positive 'bus-bar, for a given fault on the *positive* system, and for three different resistances in the B.O.T. connection, is shown clearly. Fig. 2 of the paper will help Mr. Trotter to apply this diagram in a similar way for the determination of the conditions accompanying the leak on the negative.

Mr. Trotter also asks what is the meaning of the ordinate (A_2) in the diagram, Fig. 1. It is the value of the current which must be put into the artificial leak (see reply to Mr. Russell) in order to bring the potential of the earth to that of the neutral 'bus-bar. In other words, it is the amount by which the normal positive leak is greater than the normal negative leak when both are under the same pressure of 230 volts, and is therefore $= (P - N)$. I am encouraged by Mr. Trotter's remarks to hope that the diagram given in Fig. 1 will prove useful to those engineers who like something which enables them to picture graphically what goes on, instead of having to arrive at it deductively from formulæ.

Mr. Dewsbury's experience is very interesting, as quite confirming the conclusions in the paper as to the advantage of earthing through a resistance alone, and with no fuse whatever in connection with that resistance. Mr. Taylor.

Mr. Groves makes the remark that Mr. Russell's test is more convenient than mine, and is less complicated in the formula used.

The formula for my test is—

$$F = \frac{V_1}{A_2 - \frac{V_1}{2\,\omega}};$$

the resistance in the earth connection being made equal to 2 ohms. There is no great complication about this, and I think his complaint is caused by his setting off the *two* tests I suggest—the combined insulation resistance test *and* the "discriminating" test—against the one test of Mr. Russell. But to get the same information as Mr. Russell's test gives, it is only necessary to perform the *first* part of the test (see remarks under reply to Mr. Russell), and this consists of the simple observation of (V_1), the normal voltmeter reading, and of (A_2) the current in the artificial leak when we close the circuit of the same and adjust the sliding resistance switch shown on Fig. 7 of my paper.

On the question as to whether a discriminating test is always necessary, as a day-by-day operation, I am inclined to agree with Mr. Groves that it is not. It is merely useful in enabling us to know whether the insulation of the two *outer* mains comes up to a standard—say the B.O.T. standard of a combined leak not exceeding one-thousandth of the station output—and so preventing the mains superintendent from hunting for faults on the outers which the low insulation of the neutral has led him to imagine exist there.

Mr. Ashlin suggests a more easy way of measuring the neutral leak than that employed in my "discriminating" test. Such an arrangement as he suggests it was my intention to describe on the occasion of reading the paper; but it was necessary to postpone its description to another occasion on account of the lateness of the hour.

It is easy to arrange such a circuit as Mr. Ashlin suggests, *i.e.*, with a single Leclanche cell and a voltmeter, graduated in amperes; but the difficulty is the continually-varying magnitude of the out-of-balance current of the station.

The way in which this may be overcome is as follows: Off the plate resistance shown in Fig. 7 let there be taken 11 wires or tappings, thus dividing the resistance into 10 equal parts.

Connect the free end of No. 11 wire with a source of E.M.F. of 0·2 volt (a couple of small cells of different types set to oppose one another will do), then continue it through a central-zero voltmeter, sufficiently sensitive to read 100· divisions of scale with 0·2 volt, and again continue it to the central contact of a 10-way voltmeter switch, to the other points of which are attached the free ends of the other 10 wires. If, now, the voltmeter dial has been graduated to read 0 — 100 amperes then, with the switch on stop No. 1, the voltmeter reads

Mr. Taylor. $1^{\circ} = 0{\cdot}1$ ampere; and with it on No. 10 it reads $1^{\circ} - 1{\cdot}0$ ampere, and so far any intermediate value proportionally.

If the plate resistance $= 0{\cdot}02$ ohm then, when 10 amperes traverse it, the voltmeter will read zero when the switch is on stop No. 1; if 100 amperes traverse it the voltmeter will read zero when the switch is on stop No. 10, and so proportionately for intermediate values.

Take, for an example, the case where the normal out-of-balance current of the station is only 10 amperes.

Set the switch on stop No. 1 and the voltmeter—which is graduated, as before stated, in amperes—will read zero. Now apply pressure to the neutral leak (in the manner indicated in reply to Mr. Russell), and the *increment* of current through the neutral feeders, due to the neutral leak, is read directly on the voltmeter, remembering that the dial reading in ampere must be in this case divided by 10.

If 100 amperes had been the normal out-of-balance current of the station, instead of 10 amperes, we should have put the switch on to stop No. 10, and have read the leak current *direct* in amperes.

It is not necessary that the reading should be at zero to begin with; all that is necessary is to take the difference of the two readings obtained before and after putting pressure on the neutral leak.

In conclusion, I wish to thank the various gentlemen who have taken part in the discussion for the kind way in which they have received the paper.

MANCHESTER LOCAL SECTION.

THE ARRANGEMENT AND CONTROL OF LONG-DISTANCE TRANSMISSION LINES.

By E. W. COWAN, Member, and L. ANDREWS, Member.

(Paper read at Meeting of Section, March 3, 1903.)

It is proposed in this paper, after a general review of the points involved, to deal more fully with the regulation and protection of the lines by making certain suggestions with a view to the more certain maintenance of an efficient service; and especially with some of the conditions to which long transmission lines at comparatively high pressures are subject, whether underground or overhead.

GENERAL CONSIDERATIONS.

Pressure.—The maximum pressure, so far as we are aware, which has been actually in practical operation is 80,000 volts. The Standard Co. of America have operated on one of their lines for two hours in adverse weather at this pressure without any trouble arising. There is no reason why this should be the limit of pressure, as transformers have been worked well above 100,000 volts, and with liberal spacing of the overhead wires the electrostatic leakage can be sufficiently reduced. The capacity current increasing with the pressure must of course be reckoned with, and, if necessary, compensated for by suitable reactance coils in the way referred to later on. It is with large powers and long lines that economy requires the adoption of these great pressures. It has been contended that pressures above 10,000 volts will not serve any useful purpose in this country. We think that these expressions of opinion indicate a narrow view of the future development of electrical power. The essence of electricity supply lies in its distribution, and any factor which increases the distance, the economy, and the facility with which electrical energy can be transmitted greatly widens the field of its usefulness. We are not speaking of small powers, our ideas of "bulk" embracing more than a few thousand kilowatts; we are thinking of the requirements of the power user and of the necessity for concentration of large units at the centres of supply if advantage is to be taken of the use of gas fuel. Cheapening the outside works and reducing the losses of transmission, which is the result of the use of high pressures, greatly facilitates the exploitation of the area supplied. According to the development of demand other centres of supply can be installed, the raising of the necessary capital being then greatly simplified, not to say cheapened. We should point out that the extra outlay involved in the use of high pressures is trifling; it only affects insulation of line and transformers.

There is no reason why a scheme should not provide for the supply being transmitted at a low pressure in the early stages of its career, and when the requirements of the situation justified it, the pressure could be raised merely by an alteration to the step-up and step-down transformer connections. According to Mr. Parshall, 20,000 volts may be taken as the safe limit for underground cables; the cost of insulation and the capacity of the underground cable rendering the use of higher pressures prohibitive. There is a point in favour of high voltage for underground cables which should be borne in mind. Assuming the same energy transmitted by a cable, the heat energy developed at a fault is, from one point of view, inversely proportional to the square of the pressure. We consider, therefore, that the Board of Trade should allow greater energy to be transmitted by a cable with greater pressures.

Periodicity.—After much fluctuation the practice of to-day seems to be steadying down to a frequency of 50 to 60 for alternating currents. The Pacific Coast lines in California have adopted comparatively high frequencies—the Niagara Company standing almost alone with its low periodicity. It is interesting to note that out of seventy-three power transmission installations, thirty operate at a frequency of 60 cycles or over, and twenty-eight at between 50 and 60 cycles. It must be remembered that the higher frequency increases the charging current, the impedance drop, and is not so well adapted to motors or rotaries as the lower frequencies; at the same time lighting becomes practicable and the transformers are cheaper.

Lightning.—It is necessary in some countries to make very elaborate protection against lightning discharges. Atmospheric difference of potential can best be provided against by stapling a barbed wire to the poles and frequently earthing. The increase in capacity in the cables due to this wire is said to be not appreciable. Disruptive discharges are dealt with by lightning arrestors, of which there are many designs. The essence of nearly all types is the provision of a small inductance (kicking coil) on the generator side of the earth connection, in series with which the discharge part of the arrestor is placed. A large number of spark-gaps in series with a non-inductive resistance form the essential features of this part of the apparatus. For reasons stated later on horn break lightning arrestors should be avoided.

Earthing.—There is considerable difference of opinion as to the advantages and disadvantages of earthing the neutral point in a polyphase system of distribution. It appears to us that the advantages of earthing are considerable. In an unearthed system the static capacity between wire and earth with high pressures becomes a source of danger, and this static capacity may be 83 per cent. higher than it can possibly be if the neutral of a three-phase system be earthed. When the neutral is earthed faults are immediately detected, and must be removed. On the whole, the voltage available in case of accidental contact tends to be reduced by earthing the neutral point. We learn that the Lancashire and Yorkshire Company in their electric railway scheme are earthing the neutral point, and thereby making an

appreciable saving in its cost, which is another advantage of great consequence. The Cable Makers' Association have recently standardised a reduction of dielectric thickness between conductors and earth of approximately one-third when the neutral is earthed.

CAPACITY.

The charging current required for long lines even when fixed overhead is very large. A 100-mile line working at about 50,000 volts and with a periodicity of 50 requires a charging current exceeding 2,000 kilo-volt-amps. This is equivalent to the full current load of a 2,600 E.H.P. plant. Unless the capacity is neutralised by reactive coils it becomes uncommercial to transmit powers at this pressure of less than 3,000 kilowatts. The use of high potential reactive coils, which are made preferably without an iron core, and placed as a shunt across the mains at suitable positions on the line, is a rather expensive expedient and also involves the introduction of many points of possible breakdown of insulation which are better avoided. Further these coils should be disconnected as the load comes on. The charging current on underground cables is of course much greater than on overhead. The Deptford cables at 10,000 volts take a charging current, we believe, of 45 amps. = 450 kilo-volt-amps. Large synchronous motors on the line with their field strength suitably adjusted can be arranged to neutralise the capacity of the cable, but their field strength must be varied with the load on the line. An ideal arrangement would be to balance the constant self-induction by constant capacity and the variable self-induction by variable leading load.

Though this capacity current, being expended reversibly, does not represent proportionate loss in watts, it does involve considerable loss at light loads and also results in bad regulation, the leading current causing an alteration in the ratios of the transformers and in the field excitation of the generators. It should be noted that the current required to charge cables is greater when the current curve departs from sine form, and it has been stated that the charging current may be increased from 200 to 300 per cent. when the waves are jagged. As the load increases the power-factor also increases. In one installation, having very large capacity in the cables which we were connected with, the power-factor at full load was over 99 per cent. It is often said that capacity is an advantage in supplying the magnetising current for the transformers and for neutralising the self-induction of the line. This is true, but large capacity is nevertheless the cause of far more trouble than it saves. The Manchester 6,500-volt cables have a capacity of 0·23 mfd. per mile between one core and the other two.

Loss in line.—The loss in the conductors must of course be worked out for the greatest economy in each case, with due regard to the spirit of Kelvin's Law. In long lines the loss may be as much as 50 per cent. One hundred amperes is about the limit which can be transmitted on one line from 100 to 200 miles long, owing to inductive drop which, with a 200-mile line at 60 cycles and 50,000 volts, may amount to no less than 50 per cent. The necessity for high pressures to reduce the current

upon which the inductive loss per mile depends, becomes, therefore, very evident when the length of the line is great.

Overhead and Underground Conductors.

For long distances underground cables are inadmissible, not only on account of their cost, but also because their capacity with the high pressures necessary results in an impracticably large condenser current. It has been very clearly shown by our Chairman, Mr. Earle, and also by Mr. Stewart, that a point is soon reached at which the cost of insulation is so high in proportion to the cost of copper in underground mains, that no economy results in transmitting energy at a higher pressure than a certain critical ascertained "cheapest" pressure. But this "cheapest" pressure will be further reduced by taking into consideration the reduction of charging current which will result from a lower pressure. The saving will be effected under the following heads:—(1) Reduced dielectric loss in cable; (2) charging current C^2R losses in copper of cable, transformers and generator; (3) standing losses in light-load engine which must be larger the greater the charging current. Proper value must be given to various factors, such as the hours of light load (charging current is practically eliminated at full load), reduction of condenser current due to inductive load, etc. We have worked out the capacity current at a frequency of 50 from data obtained from a length of vulcanised rubber concentric (37/15), and find that the charging current at 30,750 volts on a single 27½-mile length of such cable with the outer earthed would amount to over 4,000 apparent kw. It will be at once seen that no possible distribution could be carried out on these lines.

It appears to us that long-distance transmission lines should always be run overhead when crossing open country. Mr. Earle has calculated that the cost may be about one-third of the cost of laying the cables underground, but in addition to the saving in cost, there is the accessibility and ease of repair, and the possibility of using more economical pressures with the greater economy in running at light loads owing to the greatly reduced capacity current.

Against the use of overhead wires there are three objections:—

(1) Danger.
(2) Unsightliness.
(3) The Board of Trade?

On the question of danger we do not think that serious consideration need be given to the risk of accident from falling wires. There is a small risk, but with a well-engineered line it is very small, compared with many other risks which the community must and do submit to in the general interest. Kite-flying in the neighbourhood of high-potential lines on a wet day would become a dangerous form of amusement, and ballooning would also prove an exciting sport. There is no doubt that if an air-ship became entangled with a 50,000-volt line it would suffer rapid deterioration.

On the question of appearance, these lines would not look worse, but rather better, than existing telegraph and telephone lines.

Finally, there is the Board of Trade. In their letter some time ago to the Chairman of the London Chamber of Commerce the Board of Trade intimated that they were prepared to consider overhead schemes. We therefore consider that there is a fair prospect of obtaining consent to a form of distribution which can be, we think, readily proved to open out much greater possibilities in the direction of cheap power, which means cheaper production and consequently greater prosperity in the country.

Overhead Construction.

Poles and Conductors.—The poles are generally of wood from 35 to 40 feet in length, and spaced about 50 to the mile. In some instances steel towers are being used which get over the difficulty of the decay which takes place in the part of the pole underground. The steel towers in the case of one 60,000-volt installation in Mexico are placed 440 ft. apart. It has been stated that the cost of these towers does not exceed that of a first-class pole line. As an instance of what can be done, there is a single span of 4,000 ft. on the Bay Counties Co.'s line in California. The insulators are made of glass, vitrified porcelain, and of brownware. The latter are said to be less alluring to the sporting instinct, and the glass insulators have an advantage in their transparency, annoying the spiders which prefer to spin their nests in the dark. Porcelain must be thoroughly vitrified. A $\frac{3}{8}$ in. slab of unvitrified porcelain punctured at 17,000 volts under test, whereas a piece of well vitrified porcelain $\frac{1}{8}$ in. thick withstood 49,500 volts. The insulators for high pressures are generally made with three petticoats. For such pressures as 60,000 volts they will be about 14 in. in diameter, and placed about 10 feet apart. For 30,000 volts they will be about 7 in. diameter. Aluminium wires have been used in some cases, notably by the Standard Company in America. The weight of these conductors for the same conductivity is about half that of copper, the strength about $\frac{5}{8}$, and the diameter 30 per cent. greater. The question of durability can only be settled by time, but the lighter weight enables the spacing of the poles to be increased or the safety factor to be higher. An incidental advantage electrically is that the electrostatic leakage is less with aluminium cable, as its surface is larger.

Electrostatic Leakage.—The electrostatic leakage, taking the form of a brush discharge between wires, with high pressures is considerable, and the use of conductors of less diameter than $\frac{3}{8}$ in. becomes prohibitive.

A test on an actual line showed loss of energy due to air leakage with 47,300 volts to be 1,215 watts per mile when the distance between the wires was 15 inches. When this distance was increased to 52 inches the leakage was reduced to 122 watts per mile. With high pressures it is usual to place the wires about 10 feet apart.

Inductive Drop.—Self-induction and mutual induction must be taken into consideration, and on long lines both may have considerable

effect. Mutual induction can be neutralised to a large extent by suitable transposition of the wires, each case being worked out according to the circumstances. In the instance of two overhead three-phase systems, the mains of each system should be spiralled, the pitch of the one being three times that of the other. The mutual induction will then be zero. The drop due to self-induction is compensated for to some extent by the capacity of the line.

Electrostatic Induction.—This form of induction affects neighbouring telephone lines and may make them unworkable. It is not easily dealt with, and such lines should give each other a wide berth in order to avoid trouble.

Underground Line Construction.

Underground cables are all but universally used at the present time in this country for the distribution of electrical energy, excepting the trolley lines for electric traction. The system which has found most favour is the so-called "solid system." A typical method of laying has been adopted in Manchester, where the high-pressure conductors are laid in cast-iron troughs filled with bitumen. The figures and curves relating to cost given in Mr. Earle's paper, before referred to, must be corrected, owing to the fact that they were based upon a thickness of insulation which it was assumed the Board of Trade insisted upon. It has since been ascertained that the regulation of $\frac{1}{10}$th in. thickness of insulation per 1,000 volts does not apply to the extra-high-pressure cables, and that each case will be considered on its own merits. One cable maker informs us that he is of opinion that $\frac{1}{2}$ inch radial depth of dielectric is sufficient to withstand 60,000 volts pressure, but he is unable to say whether the insulation would withstand such a stress for any great length of time. The Cable Makers' Association have recently standardised a thickness of little over $\frac{3}{8}$ inch for 10,000 volts working pressure.

We now pass to the second part of our paper, dealing with Regulation and Protection of High Pressure Lines.

In 1896 one of the authors of this paper, in conjunction with Mr. A. Still, submitted a communication to the Northern Society of Electrical Engineers, a section of which dealt with feeder regulation with static boosters. Since that date certain improvements have been made in the variable induction type of regulating transformer, whereby its inductance and magnetising current have been substantially reduced. In the discussion on the paper referred to, Mr. Rider, Mr. Mordey, and others expressed the opinion that the system recommended was the best method of regulating. Briefly this system, which has been widely adopted, consists in connecting the feeder in series with the secondary of a transformer, the pressure across which can be varied by operating a hand wheel. In supply works where there is only one transmission line such apparatus is not needed, as the 'bus-bar pressure can readily be varied; but in cases where there are two or more transmission lines of different length or load, independent regulation of each line is necessary. There is practically no loss in

efficiency in augmenting the pressure on a line in this way, the losses in the booster being sometimes less than the saving in supplying the 'bus-bars at a lower pressure. This is owing to the core losses in the

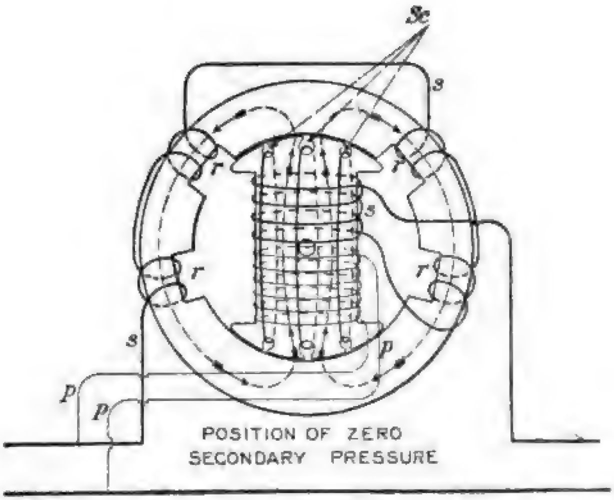


FIG. 1.

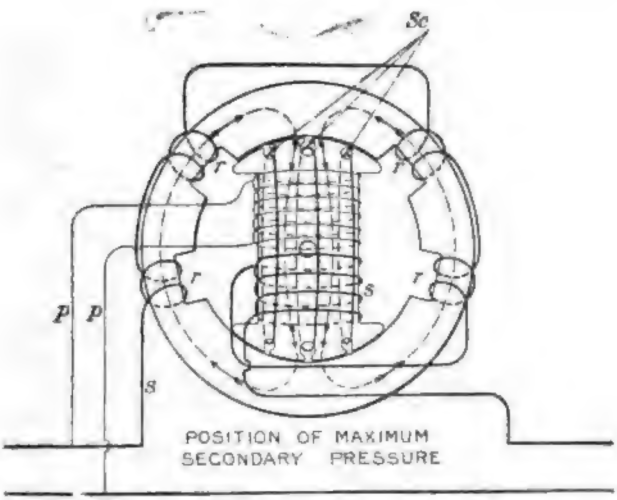


FIG. 2.

generators varying approximately as the square of the induction. The mass of iron in generators will, of course, greatly exceed the iron in the boosters.

Figs. 1 and 2 show the winding and arrangement of core of the

improved Variable Induction Transformer, in the position of zero secondary pressure. Instead of the secondary winding being wound entirely upon the ring, it is wound half on the movable core and half on the ring. The primary winding is wound as before on the movable core. The result of this arrangement is that the magnetic lines induced by the primary winding cut the half of the secondary wound on the movable core in a positive sense, and the half of the secondary on the ring in a negative sense in the relative position shown in Fig. 1. The resultant E.M.F. in the secondary is therefore nil. In Fig. 2, however, the movable core has been rotated through an angle of 180°, and the magnetic lines cut both the secondary windings in a positive sense, the resultant E.M.F. being the sum of the two, and therefore a maximum. In intermediate positions, intermediate secondary pressures are obtained.

It will be at once seen that there is practically no magnetic leakage between the primary winding and the half of the secondary winding on the movable core, and that the number of secondary turns on the iron ring being half of the total, the tendency for magnetic leakage to occur at the air-gap is proportionately reduced. The result is that there is only a total drop of six to seven per cent. on the secondary between no load and full load.

A further improvement consists in fixing shading coils on the movable core in the positions shown, and marked *s c* in the diagram. These shading coils neutralise the inductance of the secondary circuit when the movable core is in intermediate positions.

Lastly, the slots in the ring which contain the secondary coils are so placed that the area of gap between movable core and ring is as large and as equal as possible in all positions, thereby keeping the magnetising current as low and as constant as possible.

The result of these improvements has been to bring the apparatus up to a standard which leaves very little room for further improvement.

Before describing certain special apparatus for the protection of transmission lines, we have thought it worth while to discuss the dangers to which such lines may be subjected under working conditions :—

Abnormal Pressure Rise in Transmission Circuits.

A great deal has been written upon the subject of rises of pressure which take place under certain conditions in long circuits having considerable self-induction and capacity. Mathematicians have figured on the subject at length, and experimentalists have reproduced many of the phenomena accompanying line disturbances. At the same time the subject is enveloped in a certain amount of mystery, and cannot be considered as fully understood. It is usual for engineers to speak glibly of resonance and capacity effects, and they understand the effect of the equivalent of the inertia of the current in the shape of self-induction. It is generally appreciated that all three of these influencing factors combined in certain relations are responsible for the truly terrible rises of pressure which sometimes unexpectedly occur,

It is important that engineers should understand as far as possible the physics of these phenomena, and we have therefore dealt rather fully with the question, in the hope that, to a small extent, what we have written, and, to a large extent, the criticisms which we trust will follow from other engineers may tend to the elucidation of some of the mystery. In the first place, the rises of pressure are beyond question great in destructive effect. We have experienced them ourselves many times. In one case the opening of a switch on load caused the instantaneous breakdown of four transformers, and an alternator armature to flash to its field poles. In another case the rupture of a fuse in a sub-station caused the most violent rise of pressure at the transmitting end of the line, explosively destroying an electrostatic voltmeter and doing other damage. A transformer at Hastings broke down, and presumably was the cause of the simultaneous breakdown of another transformer, connected to it only through the station 'bus-bar by a three-mile length of conductor. On the Altrincham circuits it used to be a regular custom to examine the fuses in all transformers within a certain radius of any one transformer in which they had blown, and it was often found that a number of fuses had blown simultaneously. At the Paris Exhibition a man drove a nail into a cable, and it was simultaneously punctured at a point a mile distant. A rise of pressure of ¼ to ½ a million volts has been observed on a half-mile H.T. cable with considerable self-induction when the circuit was broken, the normal pressure being only 10,000 volts.

Passing over the opening of circuits of large self-induction *per se*, such as field coils, etc., we will first consider the case of opening a circuit having self-induction and also capacity to an appreciable extent. In this case the capacity takes the place of the arc formed at the switch or fuse break as the equivalent of a relief valve tending to reduce the rise of pressure, and at first sight it might be thought that the presence of capacity was just what was wanted. Indeed, it has been pointed out again and again that underground cables having necessarily more capacity than overhead, are freed thereby from such severe rises of pressures. But the arc, when steady and maintained, is a far more efficient relief to the line than capacity. In the arc the electro-magnetic energy stored in the cable is discharged through resistance, and thereby doing work, is dissipated. But if capacity exists, the arc is abruptly extinguished owing to the rise of pressure sufficient to maintain it being checked by the flow of current into the condenser. The full amount of electro-magnetic energy stored in the cable will therefore be converted into electrostatic energy in the condenser. At the moment the cable was opened the condenser was charged by the normal pressure of the circuit, so that the charge it receives from the electro-magnetic energy of the line will, according to its measure, increase its pressure. It is easy to calculate what this rise of pressure will be if the data be given. But that is not all, the condenser differs from the arc in that it does not dissipate the energy put into it, but instantly returns it to the circuit to be reconverted into electro-magnetic energy. The process is then reversed again, and an oscillation set up between the electrostatic and electro-magnetic state at a rate depending

upon the natural period of oscillation of the circuit which will be slower the longer the circuit may be. The frequency will in all cases be very much higher than the normal frequency of the supply to the circuit. It has been shown that under certain conditions a pressure rise in *volts* may occur of *two hundred* times the interrupted current in *amperes*, and these conditions are such as may occur on commercial transmission lines.

It thus appears that to draw out a long arc at the switch contacts is the safest way of opening a circuit of high inductance, and in our opinion with continuous currents this is the best practice. With alternating currents, however, a new disturbing factor is introduced by the open-air arc. It is well known that an arc between carbons will emit a musical note if it be shunted by a condenser and arranged in series with a very small amount of self induction, such as will be obtained from the conducting leads or a coil of wire. This musical note is due to the arc being intermittent, and the rapidity of these interruptions may, at any rate in the case of an alternating-current arc, be very great—3,000 to 4,000 per second. Here then are all the conditions which are well known as the cause of pressure rise. In an induction coil or transformer the induced pressure increases proportionately to the frequency of intermittence of current or of alternation when the induction in the core is constant.

The intermittent arc at switch break has been compared to the Wehnelt Interrupter, the self-induction and electrolytic polarisation of the latter being replaced by the self-induction and capacity of the former. In one installation we have been associated with, the capacity of the mains was no less than 87·8 microfarads. It is not difficult to get some idea of the volcanic conditions of a circuit under such conditions, the roaring arc at switch or fuse kicking waves of E.M.F. into the circuit, which are met by surging waves of varying periodicity, travelling about the cables and their branches at a speed something less than that of light, causing resonant effects where their crests coincide and rises of pressure at every terminal point and every point where there is a change to greater inductance and less capacity. Such a storm of colliding E.M.F.'s will break down the insulation of any system. Arcs have been drawn out to a length of 35 feet under such conditions with 40,000 impressed volts and 150,000 volts pressure observed while the arc was flaring. We have no room on modern switchboards for arcs 35 feet in length, and to use an open break switch on high-potential circuits having appreciable self-induction and capacity is bad engineering. We may mention here that metal arcs are much worse than carbon, the conducting vapour of the latter tending to prevent the intermittent extinction of the arc. Soft carbon break would be the safest, and there is an open field for switch designers to construct an air break switch, the arc of which shall be maintained at gradual increasing resistance, and the first break in which must be the last. A low resistance intermittent arc is the worst of all for producing the above effects.

On all high-potential alternating-current circuits the oil break switch is being generally adopted at the present time. But an oil break switch,

though it prevents the formation of the dangerous intermittent arc, appears to be an unscientific method of opening any circuit with appreciable self-induction. The self-induction of the circuit being the same, it seems to us to be equally bad to open an alternating-current as to open a continuous-current circuit abruptly, whether under oil or by magnetic blow-out. It is true that there are many chances against opening the alternating current at its mean value, but at the same time, are there not some chances that it will open at the wave crest which is, with a sine curve, 41 per cent. higher than the mean? We are unable to see any physical difference between the suddenly opened alternating-current and the continuous-current circuit in respect to rise of pressure due to the accumulated electro-magnetic energy with which the circuit is linked if the current is the same in each case. At the same time, if it can be shown that the oil break switch *always* opens the circuit at a point in the current wave much below the mean, our objection would be withdrawn. We do not in any case contend that the oil break switch is not the best form for engineers to adopt at the present time for very high pressure circuits which must be opened under load, though water break is safer in cases where space can be afforded.

We have dealt with the most important results of current surging first, but there are other causes of rises of pressure which must be borne in mind. There may be a resonant rise of pressure, especially if the curve of E.M.F. and current departs much from true sine form. These rises, which are steady when the cause is steady, are due to interference between the generator waves and the waves of oscillation in the cable. It can only take place when there is capacity and self-induction, but may be set up by the fundamental waves of the generator or by odd multiple harmonics or overtones thereof. Resonant effects have been observed with continuous currents owing to slight waves being generated by the commutator. Rotaries have been known to produce resonance, their commutators being again the cause. The general result, however, of steady resonance is not serious, and the rise in step-up transformers due to the leading current will in general be many times greater than that due to resonance. Regulation is not easy when resonance occurs only at some critical speed.

While the opening of a circuit under load is the worst condition for causing rises of pressure, rises will also occur when an unloaded line is opened or closed. According to many authorities on this subject the rise cannot exceed double the normal pressure under these conditions, and it is easy to follow the reasoning on which this conclusion is based. When the switch on a "dead" circuit is closed, the electrostatic energy stored in the cable may be equal to or greater than the electro-magnetic energy stored in the ether surrounding the cable by the current flowing to charge it. This latter energy will be converted into electrostatic when the impressed E.M.F. of the circuit equals the back E.M.F. of the condenser, the result being that a double quantity of electricity can be forced into the condenser, and the final pressure may consequently be double the normal. In the same way opening an unloaded circuit may result in a rise of E.M.F. double the normal pressure. As a matter of fact, however, a higher pressure than double the normal has been

recorded when closing the switch of an unloaded line of 44 miles in length. This increased rise is probably due to some coincidence between the crests of the impressed waves of E.M.F. and the crests of the waves of E.M.F. of high frequency, which accompany the natural oscillations in the cable.

Reviewing the whole question, one is forced to the conclusion that circuits having appreciable capacity and self-induction should not be switched on or off, whether loaded or unloaded, suddenly. All surging currents should be avoided, and fuses should be used only when the natural reactance of the circuit is too small to prevent a dangerous rise of current.

In the next section of our paper we describe various methods of switching currents on and off gradually, which have been devised to prevent the system from being submitted to dangerous pressures.

Cable-charging Apparatus.

The earliest cable-charging apparatus of which we have any knowledge is that installed at Deptford, Willesden, and in other places. It has been described before, and we will, therefore, only briefly refer to it now. It consists essentially in closing the circuit through high inductance, which inductance is gradually removed by manipulating a liquid resistance in series with a secondary winding on the inductance coil. An ordinary transformer can be used. Mr. G. W. Partridge informs us that it is important with this apparatus to short-circuit the primary winding as soon as the full E.M.F. is indicated by the circuit voltmeter. If this is not done, he has found that a rise of pressure 50 per cent. above the normal may occur on the circuit. This is probably due to the circuit reaching the condition of resonance. This arrangement has recentiy been objected to on account of the probability of resonant rise of pressure occurring with it, but it seems to us that as the pressure of the circuit is under observation when the apparatus is being used the danger is small. The fact that this apparatus has been in daily use at Deptford since 1892, and Mr. Partridge informs us is working perfectly satisfactorily, is, we think, good reason for regarding it with confidence.

Another method of charging is to run up a separate motor alternator on the circuit, and then to synchronise and parallel. The chief objection to this system is the time it takes to perform the operation, and the apparatus must also be somewhat complicated and costly. This system is in use in Manchester and elsewhere.

A third method is one which one of the authors worked out some years ago. It consists in using a regulating transformer of the type described in the section of this paper dealing with "Regulation." The secondary is wound to give the full E.M.F. of the circuit when the movable core is in the position of maximum effect, and the primary is excited from the main 'bus-bars. Fig. 3 shows the arrangement of connections for single-phase working. The system is equally applicable to the polyphase supply. In the figure, A_1 and A_2 are the 'bus-bars, R is the regulating transformer, C is the circuit, and B_3 is the

charging 'bus-bar. When it is desired to charge a circuit, it is plugged on to the charging bar by means of the plug P. The regulating transformer is then operated by a hand-wheel until its secondary volts equal the main 'bus-bar volts. The main switch is then closed, and the plug withdrawn. The whole operation can be effected in a few seconds, and it has the advantage of being reversible, that is to say, circuits can be gradually switched off as well as gradually switched on. It occupies a very small space, only one transformer being required for any number of circuits. As the transformer is only excited for a very short time it is safe to work at a high induction in the iron and a large current density in the copper. Messrs. Cowans have used a standard 15 kw. regulating transformer (Fig. 4) for 150 kw. charging current, the temperature rise being inappreciable after five minutes at full load. They have also been made to give, in conjunction with a step-up transformer, 60,000 volts secondary pressure.

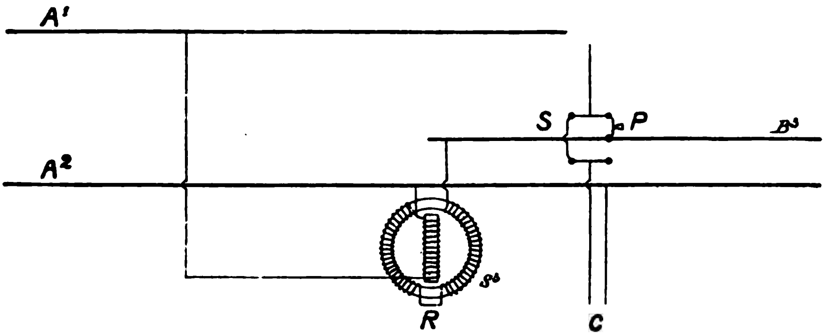


FIG. 3.

The last arrangement for cable-charging we propose to describe is a variable water resistance method. The system has been recently worked out by Messrs. Ferranti, and the apparatus is illustrated in Fig. 5.

It consists of a metal containing vessel A supported in a cast-iron case B, on and by insulators C¹, C², C³. In the containing vessel are rigidly fixed two porcelain tubes D¹, D², these tubes being about 5 feet long by 3 inches internal diameter. Each tube contains an ebonised iron rod E, carried at its upper extremity by an insulator D. At the lower end of this rod is a piston F, upon which is fixed a metal cap G. This cap is electrically connected to the terminal H by a spiral tape conductor I. The piston F fits into a well at the bottom of the containing vessel, which is filled with mercury. A gauge glass J enables the height of the water to be seen through a glass window in the outer case. The height of this water is normally kept about 3 feet above the bottom of the containing vessel, and the total upward travel of the rods is 2 ft. 10 in. The apparatus illustrated is intended for use

in connection with a two-phase system, one tank being provided for each phase. The ebonised rods are carried at the extremities of a connecting crosshead. The weights K tend to lift the crosshead, but this is prevented when the rods are in the lowest position by a catch controlled by an electric magnet L.

The method in which this charging gear is inserted in circuit with the feeders is practically similar to that shown in Fig. 2. To charge a feeder the catch is released, thus allowing the balance weights to lift the crosshead and so increase the length of the column

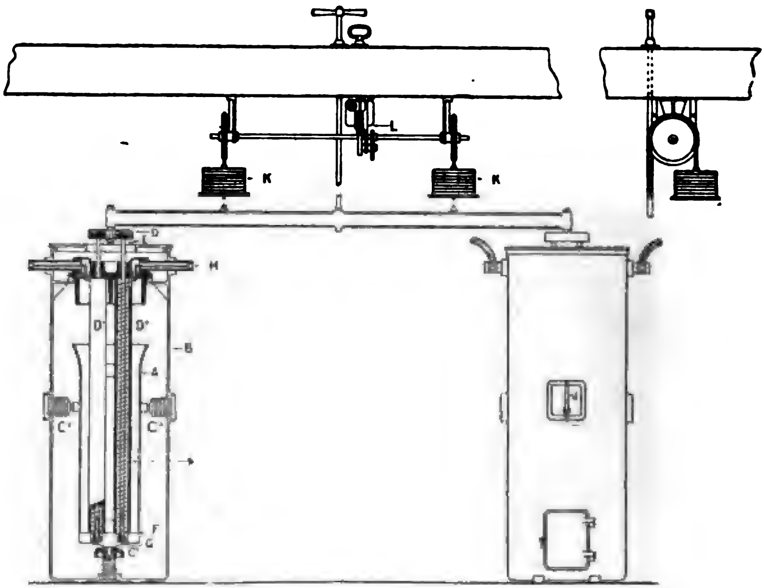


FIG. 5.

of water to its maximum. The feeder switch is set at half-cock, thereby connecting the feeder to a small auxiliary 'bus-bar corresponding to the synchroniser bar in the "Ferranti" standard generator switch-gear. This bar is connected to one terminal of the cable-charging device. The other terminal is connected to the main 'bus-bar through a fuse and switch on a special feeder-charging-panel. The water resistance in series with the feeder is then gradually reduced by pushing down the crosshead to its extreme limit of travel. This is done by a length of rod terminating in a handle above the switchboard gallery. When all the resistance has been cut out the catch comes into operation and holds the crosshead down; the feeder switch is then finally closed. A hand release to the catch is provided to enable the apparatus to be used for charging another cable in a similar manner. To discharge a feeder the rods are pushed down

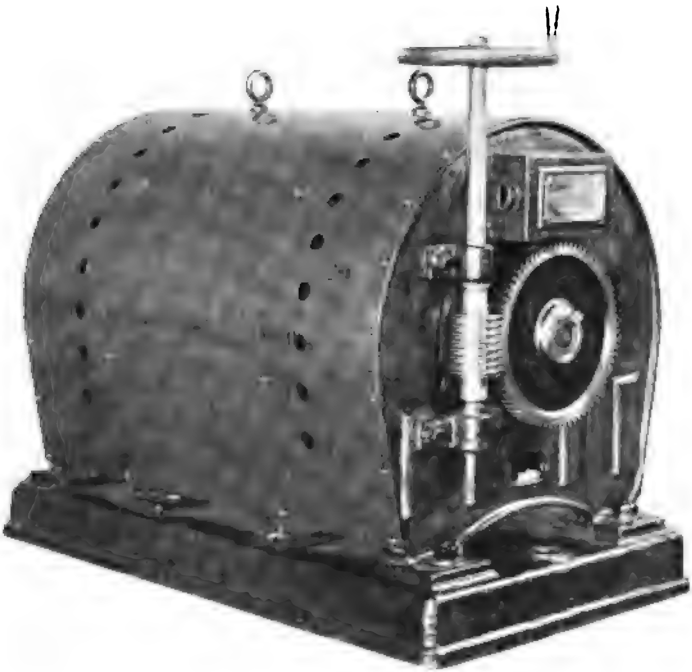


FIG. 4.

to their lowest position (if they have not previously been left thus), and the feeder switch is pulled out on to the second contact. In this position the magnetic release trips the catch and thus allows the weight to descend and gradually increase the length of the column of water. The operation is finally completed by opening the oil break switches on the feeder charging panel. A plug switch is provided for isolating purposes only.

Duplication of Transmission Lines.

Without question every high-potential line should be duplicated. The Board of Trade in general insists upon this being done. These

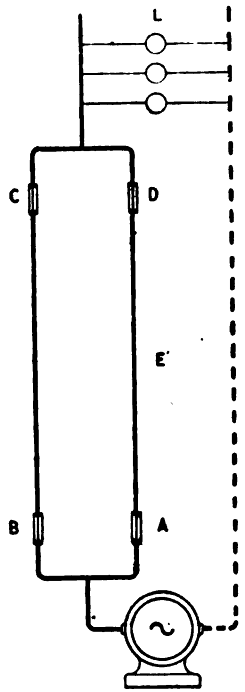


Fig. 6

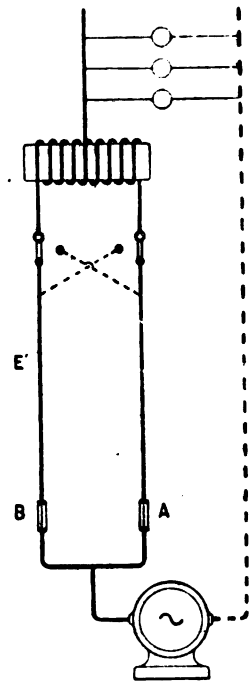


Fig. 7.

duplicate lines should be run in separate ducts if laid underground, and on separate poles if overhead. It is not safe to work on a high-potential line while any of the wires on the cross arms are alive.

Some engineers have held the view that to ensure continuity of supply one of the lines should be kept as a spare—that is to say, the duplicate line should not be coupled in parallel.

When it is remembered that the line losses are proportional to the *square of the* current, it will be clear that the losses in transmission will

be four times as great if the spare main is kept idle. It will be evident, therefore, that the difficulties arising through coupling the mains in parallel must be very serious to induce engineers to increase their line losses fourfold rather than face these difficulties. A system cannot be considered efficiently duplicated unless arrangements are made for reliably disconnecting the short-circuited feeder from the system, leaving the supply maintained through the healthy feeder. Many attempts have been made to do this by inserting fuses at each end of both of the feeders. These fuses should evidently all be of the same capacity, as it cannot be foreseen that any one of these will be required to carry more or less than the other. Now, should a fault occur at E′, Fig. 6, fuse A will certainly be blown first. Current will then feed back through fuses B, C, D, but B, C have now to carry the whole of the current to the load L, in addition to the current necessary to blow the fuse D; as a consequence, fuse B or C is almost certain to be blown before fuse D, and a complete interruption of the supply will occur.

This interruption would not be so serious if the attendants at the generating station, and at the distributing centre, were able to at once disconnect the faulty main and continue the supply through the healthy main; but this they cannot do because they have nothing to indicate, without testing, which main has failed. As a consequence considerable time must elapse before the supply can be continued. When the line has ultimately been cleared, if synchronous motors are used in the converter stations these will all have to be run up and paralleled, and after this has been done, if all consumers have left their motors connected to the supply, a very heavy starting current will be required to get them away. In connection with several of the power schemes in the States consumers have been requested to disconnect their motors whenever an interruption to the supply occurs and to keep them off until the supply is recommenced, and then switch them on one by one.

The loss arising through the stoppage of many hundreds of motors for only a quarter of an hour is liable to be extremely heavy.

It is not then surprising that some engineers have considered it advisable to keep one of their transmission lines purely as a spare, so that the attendant at each end of the line can switch over from the faulty main to the spare main. This can sometimes be done sufficiently quickly to prevent any appreciable slowing down of induction motors and rotary converters.

A perfect duplicate transmission line should, we think, fulfil the following specification :—

(*a*) It should be possible, without increasing the risk of an interruption to the supply, to keep both lines in continual service, thereby reducing the line losses by 75 per cent.

(*b*) A fault on either line should have no effect on the remaining line, other than causing it to carry the whole load previously borne by the two.

(*c*) The supply to the distributing centre should not be even momentarily interrupted, as the shortest interruption is sufficient to cause synchronous motors to fall out of step.

A system devised some years ago by one of the authors which is in use in this country and in the States is to place return current, or discriminating cut-outs, at the distributing end of the transmission lines in place of the fuses C and D, Fig. 6.

This system meets the requirements of the case for high-resistance faults, but difficulties occur with low-resistance alternating-current faults.

Another defect which the above arrangement shares with a system protected by fuses alone is that immediately the fuse on the power-station side of the fault has blown, the whole of the current to the short will be thrown upon the healthy main, and if the cut-out or fuse at the distributing end of the faulty main operates, when it will be required to break this heavy short-circuit current with consequent line disturbance.

A simple device for the protection of duplicate mains is illustrated in Fig. 7.

It will be seen that the feeders are connected together at the distributing end by a choking coil, wound entirely in one direction. The supply to the load is taken off from the centre of this coil.

Under normal conditions, the current divides equally between the two feeders and the two halves of the choking coil, but the current from one feeder flows round the iron in one direction, and from the other feeder in the opposite direction, and as a consequence the winding is perfectly non-inductive, and the only resistance to the flow of current is that due to the ohmic resistance of the circuit.

Should a fault now occur at say E′ the fuse B will be blown, and the current will tend to feed back towards the short through the choking coil at the distributing end of the lines. This current will, however, be entirely in one direction, and the choking coil will, in consequence, become a highly inductive resistance, and will prevent a heavy current flowing to the short. The supply will not be even momentarily interrupted, but it will be maintained at half-pressure only, so long as the faulty main is connected to one side of the choking coil. The attendant in the distributing station will, however, be able to instantly see from the instruments which feeder has broken down, and no time need be lost in switching this off and leaving the supply maintained through the healthy feeder alone.

It will be evident that when one feeder only is left connected, the choking coil must either be short-circuited or must be so connected up to the one main as to cause the current to divide equally between its two halves. The simple two-way switch shown in Fig. 7 may be used for this purpose.

No automatic cut-outs of any description are necessary with this device, as even if the attendant is not at hand to instantly operate the switches no further damage will result to the system, and the supply will be maintained at half-pressure. If, however, it were possible to automatically operate the two-way switch at the distributing end of the lines there would certainly be some advantage in doing so even in cases where an attendant is normally in charge, and for small sub-stations in which there are no attendants, some automatic device would certainly

make the arrangement more complete. It is believed that the automatic release shown in Fig. 8 will prove to be perfectly reliable, and it is so simple and free from delicate and moving parts that it appears scarcely possible that it should get out of order.

Two small transformers are connected up as shown in the diagram between the two high-tension feeders. Under normal conditions the direction of the current in these windings will be as indicated by the arrow-heads; and this magnetising force will tend to cause a flux to

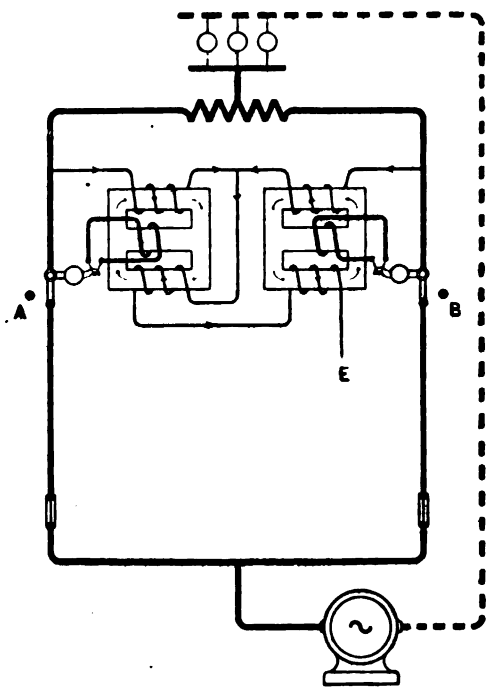


FIG. 8.

circulate round the outer limbs of the transformer. There will obviously be no tendency for magnetic flux to flow through the centre limb upon which the secondary winding connected across the copper fuse wire supporting the weighted switch is wound. Should, however, one of the feeders break down, the two small transformers will be fed from the remaining healthy main only, and the direction of the current and resulting flux will be as shown in Fig. 9. It will be seen that the flux in the transformer controlling the switch on the healthy main remains as before, but in the other transformer the flux will be diverted through the centre limb, and a heavy current will be induced in the copper fuse supporting the weighted switch on the faulty main, thus causing this to

open and instantly disconnect the fault, leaving the supply maintained at normal pressure through the healthy main.

In Figs. 8 and 9, the controlling transformers are connected to earth at E, and the contacts A and B are connected respectively to the opposite feeders.

The system described above, which has been recently shown in practical operation to a number of engineers at Hastings, appears to us to fulfil the three requirements specified above at a reasonable cost.

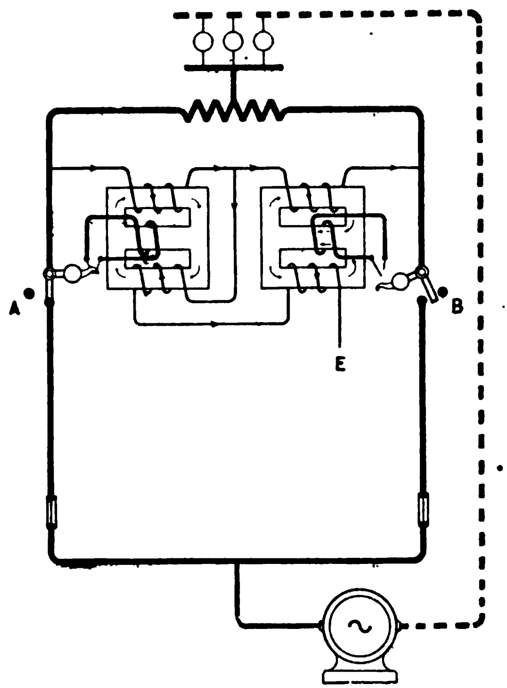


FIG. 9.

Current Direction Indicator.—A modification of the discriminating transformer referred to above may be used with alternating-current generators connected in parallel for the purpose of indicating whether a generator is feeding the 'bus-bars or receiving current therefrom. Without some device of this description the attendant has nothing to indicate, in the event of a failure, which generator to switch out, as the fault will cause the ammeters on both the defective machine and on the remaining healthy machines to indicate an excess current. Serious interruptions have resulted from this cause.

The discriminating transformer is in this case connected up as shown in Fig. 10. Red and green lamps, A and B, are connected

respectively across the terminals of two secondary windings. A primary winding C is connected directly across the 'bus-bars or across any secondary circuit excited from the main 'bus-bars. The effect of this primary winding is to induce a magnetic flux in the core of the transformer in the direction indicated by the thin arrows. A second primary winding D consists of one or two turns inserted in series with the generator connections. The effect of a generating current in this winding is to induce a flux in the direction shown by the thick arrows. It will be seen that the fluxes due to the two primaries oppose each

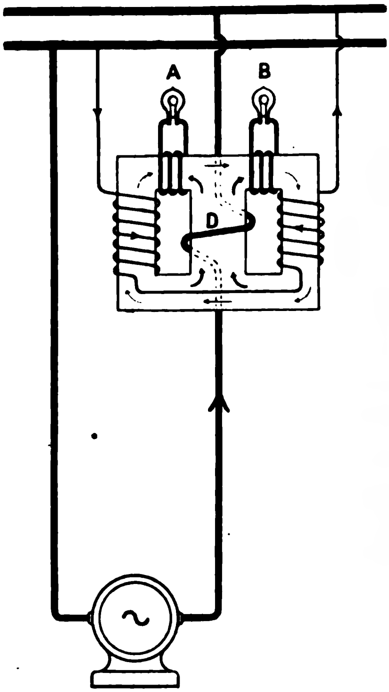


FIG. 10.

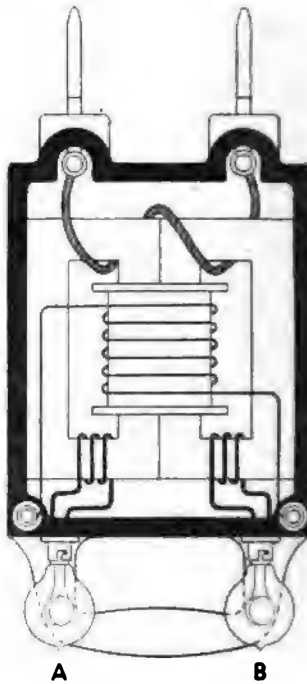


FIG 11.

other through the secondary connected to the red lamp, and assist each other to light the green lamp. Should the generator fail, the direction of the series flux relatively to the shunt flux will be reversed, and as a consequence the green lamp will be extinguished and the red lamp lighted. This current-direction indicator has also proved of great assistance in getting machines out of parallel.

Fig. 11 shows the current-direction indicator fitted into the fuse pot of a Ferranti switchboard. This forms a simple arrangement in cases where fuses are not required in the generator panels.

We trust that the importance of the subject will be accepted as an

excuse for the length of this paper. We are hopeful that, by co-operation between all who are interested, manufacturers, consulting engineers, and capitalists, Great Britain may, in due course, take the position in Long-distance Power Transmission she has held for so long in Long-distance Telegraphy.

We wish to express our thanks to Messrs. Ferranti, Mr. F. Pooley, Mr. W. B. Esson, and Mr. Preece, all of whom have kindly furnished useful particulars.

Mr. H. C. GUNTON did not agree with the authors on the earthing of the neutral point of the three-phase system. A case had recently come under his notice in which a man had received a shock from one of the arms of a 6,000-volt system and had recovered from the shock. This system was not earthed; had it been so, undoubtedly the shock would have proved fatal, whereas he had only received a condenser discharge. The use of a motor-alternator for charging the feeders, and discharging them, was found very satisfactory, and the operation could be quickly performed. There should always be duplicate mains (feeders), but in some cases it was not advisable that they should be run in parallel. Where, for instance, the mains fed a sub-station from which lighting and traction were supplied, it would be found advisable to use one feeder for lighting and one for traction, instead of running the two in parallel; should one break down, the other could, of course, be used for the whole supply. Double duplicate mains would be very costly. Mr. Gunton.

Mr. F. POOLEY thought the capital cost of some power companies could be reduced by having portable transforming apparatus. For instance, where the supply included seaside towns with a summer peak, and manufacturing towns with a winter peak, the apparatus could be used for the two cases. The cost of cables could be reduced if it were taken that the dielectric did not require to be proportionately thick with the higher voltages. He thought that the barbed wire run parallel to the transmission lines to overcome the effects of lightning, as described in the paper, would increase the capacity. The length of life of the line could be covered by a 5 per cent. depreciation fund, if the poles were well creosoted. The cost of aluminium wires worked out about the same as copper, but the poles could not be distanced to any appreciably greater extent with the former. Mr. Pooley.

Mr. H. W. CLOTHIER said that the authors had dealt with several important features of alternating-current working. He considered that the flare switch for alternating-current working was obsolete. The magnetic blow-out system in continuous-current working was bad, owing to the tendency of the voltage to rise on the sudden breaking of the circuit. A question of vital importance was that of cable charging; there was much obscurity, and though there were numerous calculations and theories of what happened when a high potential was suddenly switched on or off a cable, there were few actual records of results. In America and in several British stations no "charging" appliances were used, and yet they had heard little of disastrous effects. Perhaps they were paying too much attention to the subject? Mr. Clothier.

Mr. Clothier. He would like to know what were the limits before "cable charging" became advisable.

Mr. Nisbett. Mr. G. H. NISBETT was sorry that the first part of the paper consisted of an appreciation of overhead as against underground cables. He thought that what was often said of overhead wires must be taken with a grain of salt. A number of objections, more or less reasonable, were cited against overhead mains, and he concluded that overhead wires were a relic of barbarism. It was unfortunate that cable-makers did not know to what stress their cables would be subjected. In one instance, where the cables had to carry current at a pressure of 5,000 volts, it was found they were subjected to a pressure of from 12,000 to 13,000 volts every time they were switched on or off. Engineers should specify a maximum rise of voltage, and see that this was kept to; also, he would emphasise the importance of the alternator curve being as nearly a sine curve as possible. He agreed with the authors that it was advantageous to earth the neutral point of the three-phase system; by this means a saving of 15 per cent. could be made on the cost of the cables.

Mr. Coubrough. Mr. A. C. COUBROUGH noted with surprise that the authors thought the single-phase alternating-current system could come into use again. The only chance for that system would be by the adoption of series-wound single-phase motors, and then probably a two-phase generating system would be adopted. The only sound reason for adopting a two-phase system was the possibility of using mains that had served for a single-phase system. Frequencies were steadying down, 60 cycles being now the upper limit, and the lower limits were fixed by the requirements for satisfactory lighting; probably 40 cycles would be found best for all-round purposes. Generators, when taken in conjunction with their driving motor, varied very little in cost with different frequencies, and the advantages of smaller capacity, less charging current and lower impedance drop, were with the lower frequencies. Both arc and incandescent lighting were suitable at 40 cycles. More knowledge was wanted of the various phenomena accompanying the disruption of high-potential alternating-current circuits; he would suggest that a possible combination of an oscillograph and a cinematograph camera might be useful.

Mr. Kemp. Mr. J. P. KEMP did not agree with the earthing of the neutral point of the three-phase system; this would necessitate more insulation on the generators, and would reduce the safety-factor of the system. Cases in which men touched one of the arms of H.T. non-earthed three-phase combinations, and were not killed, were evidenced as proof of this. A method of charging cables by means of a step-up transformer and motor alternator, which had been in operation nine months, was very satisfactory. The Board of Trade required tests to be made at 1½ times the working pressure, and the "charging" plant had been most useful in this respect. The time taken to charge up a feeder was about forty-five seconds.

Messrs. Cowan and Andrews. Messrs. COWAN and ANDREWS replied very briefly to the points raised. From the statements made in the discussion, Mr. Cowan was prepared to modify his view on the earthing of the neutral point of the

three-phase system when the pressure and condenser capacity of the cables were within moderately safe limits, as appeared to be the case in Manchester. There was always the danger, however, that a fault might be allowed to remain some time unrepaired when the neutral was not earthed, and in this case the danger was increased by not earthing. The increased capacity due to barbed wire for protection of transmission lines from lightning, was said to be inappreciable. He thought the question of pressure rise in cables must be a matter for experiment. He was at a loss to understand why in some cases in America the frequency had been raised instead of lowered. Mr. Andrews thought that where a sub-station supplied current for both lighting and traction, duplicate mains for each should certainly be used. Messrs. Cowan and Andrews.

NOTICE.

1. The Institution's Library is open to members of all Scientific Bodies, and (on application to the Secretary) to the Public generally.

2. The Library is open (except from the 14th August to the 16th September) daily between the hours of 10.0 a.m. and 6.30 p.m., except on Saturdays, when it closes at 2.0 p.m.

An Index, compiled by the late Librarian, to the first ten volumes of the Journal (years 1872-81), and an Index, compiled under the direction of the late Secretary, to the second ten volumes (years 1882-91), can be had on application to the Secretary, or to Messrs. E. and F. N. Spon, Ltd., 125, Strand, W.C. Price Two Shillings and Sixpence each.

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No. 163. ISSUED AUGUST, 1903. INDEXED VOL. 32 [PART 5].

JOURNAL

OF THE

INSTITUTION OF ELECTRICAL ENGINEERS.

NOTICES.

This Part (No. 163) is the last number of Vol. 32, and, as usual, there will be no further issue of the Journal until the end of the year.

~~The Index to Vol. 32 is issued herewith.~~

Publishers' Cases for binding Vol. 32 will shortly be ready: if ordered with remittance accompanying order before September 30, 1903, the charge will be 1s. each. After that date the price will be 1s. 6d. each.

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By order,

W. G. McMILLAN,

Secretary.

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VOL. 32. 1903. No. 163.

The Three Hundred and Ninety-fourth Ordinary General Meeting of the Institution was held at the Society of Arts, John Street, Adelphi, W.C., on Thursday evening, May 7th, 1903—Mr. ROBERT K. GRAY, President, in the chair.

The minutes of the Ordinary General Meeting of April 30th, 1903, were, by permission of the meeting, taken as read, and signed by the President.

The names of new candidates for election into the Institution were taken as read, and it was ordered that the names be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

From the class of Associates to that of Associate Members—

John William Gibson. | Jas. Noel C. Holroyde.
Joseph P. McMahon.

Messrs. C. W. Barnes and R. Tervet were appointed scrutineers of the ballot for the election of new members.

Donations to the *Building Fund* were announced as having been received since the last meeting from Messrs. W. S. Entwistle and E. M. Malek ; and to the *Benevolent Fund* from Mr. W. S. Entwistle, to all of whom the thanks of the meeting were duly accorded.

The following papers were then read :—

APPLICATIONS OF ELECTRICITY IN ENGINEERING AND SHIPBUILDING WORKS.

By A. D. WILLIAMSON, Member.

So much has been written on the subject of electric driving that it is difficult to avoid repetition. The author will confine himself to facts within his own experience, and not attempt to introduce published results for which he is not responsible.

The plant which will be described in this paper has been erected in the works of Messrs. Vickers, Sons and Maxim, Limited, and amounts in the aggregate to about 22,500 B.H.P. of generators and motors.

In 1896 Messrs. Vickers were commencing some considerable extensions to their works, partly by building a number of new shops, and partly by acquiring a shipyard at Barrow-in-Furness and Small Gun works at Erith, resulting in an increase in the number of employés from about 3,000 to nearly 20,000 during the four or five years following 1896. The great convenience of the motor-driving system soon became apparent in connection with the rapid extensions. Generating plant was ordered well in advance of actual requirements, and the speed at which new shops were erected and started was limited only by the time taken to deliver the structural steel work and machines. To quote one instance of this, the South Gun Shop, now covering a ground space 660 feet by 200 feet, was built in a series of seven instalments, each complete and working as soon as it was roofed over, movable corrugated iron ends being erected to keep the weather out. The whole shop now forms one of the finest machine shops in the world, and to all appearances might have been built complete at one operation.

The first power-house was situated fairly centrally, and contained four direct-driven sets of 160 k.w. shunt dynamos and 250 B.H.P. compound non-condensing engines by Siemens and Belliss respectively. The original intention was to use the current chiefly for cranes and special armour-plate grinding machines which were difficult to drive otherwise than by motors. At the same time, however, a new gun shop was being built, and the opportunity was taken to apply motors, one to each of the machines, most of which were large and required from 5 to 10 H.P. to drive them.

The success of the electric driving system under all the conditions in which it was tried determined the directors to apply it to all the extension work and, as opportunity occurred, to replace the less efficient isolated steam plants.

Then, the first 1,000 H.P. power-house being loaded to its full capacity, a larger power-house was built, on the south side of the works, having a capacity of 1,325 k.w. As much ground was given for a site as could be spared, and it was thought that the two power-houses together would be quite large enough for the whole of the works when all extensions were completed.

Later, however, it was found necessary again to increase the size of the works, and this, added to the adoption of the Vickers high-speed tool steel and the additional power taken by the machines in consequence, rendered a third station necessary, containing one 350 k.w. set and two 200 k.w. sets.

The total plant capacity at the Sheffield works is therefore 2,800 k.w., and the details of the three sets of plant are shown in the following table:—

1. *North Power-house*—640 *k.w.*

   Four engines, 250 B.H.P. each, compound non-condensing, 360 r.p.m.

Four dynamos, 220 volts, shunt, bi-polar Siemens.

Boilers.—Two Lancashire, two marine type, 160 lbs, fitted with Ellis & Eaves' induced draught and Bennis stokers.

Feed heater, Berryman; temperature of feed about 200° F.

2. *South Power-house*—1,325 *k.w.*

Four Engines.—Three each 480 B.H.P. tandem compound condensing, Belliss enclosed type, three cranks, speed 300 r.p.m. with 25 per cent. overload capacity.

One 530 B.H.P. triple expansion Belliss enclosed condensing engine, speed 340 r.p.m. with 20 per cent. overload capacity.

Four Dynamos.—Three each 325 k.w., shunt-wound, 220 volts, 6 poles, British Thomson Houston Co.

One 350 k.w., 8-pole shunt, 340 r.p.m., by Vickers, Sons, and Maxim, Ltd.

Boilers.—Six Babcock and Wilcox, each evaporating 6,000 lbs. of water per hour, with superheaters giving about 40° F. superheat measured at the engine separators, 160 lbs. pressure.

The stokers are of the chain grate type, driven by 5 H.P. motor.

Economiser.—One Green's Economiser, 288 tubes, driven by a 1½ B.H.P. motor, giving an average feed temperature of 260° F.

Condensers.—Three Wheeler Admiralty type, connected to a common exhaust main so that any one or all may be used as required.

Feed Pumps.—Weirs.

Oil Filters.—Harris.

Steam Pipes.—Steel, weldless. A complete duplicate system of pipes, each main being connected to each engine and each boiler, allowing repairs to be made on the idle main while the plant is at work.

Pipe Covering.—Magnesia sectional.

Cooling water for condensers is pumped from the River Don by a vertical turbine pump, driven by a 5 H.P. motor.

3. *West Power-house*—750 *k.w.*

Similar in general design to the others, but containing—

One 350 k.w. Vickers dynamo, 220 volts, 340 r.p.m.

One Belliss 530 B.H.P. triple expansion engine.

Two Bruce Peebles 200 k.w., 220-volt generators.

Two Sissons compound engines, by Markham and Co., Ltd., 350 r.p.m.

Lancashire boilers, 7′ 6″ × 28′.

One Schmidt separately fired superheater, giving about 250° F. superheat: Not yet started at time of writing.

Two watertube boilers are shortly to be put down, each to evaporate 12,000 lbs. of water per hour.

4. *Erith.* In 1898 the works of the Maxim Nordenfeldt Co. were purchased, and the old system of belt driving from one main engine was replaced by electric power. A power-house was built containing 600 k.w.

Four Belliss and British Thomson Houston sets, each 150 k.w. and 250 B.H.P., 220 volts, 360 r.p.m, with Wheeler condensers and multitubular boilers, 160 lbs. pressure.

As the works were at this time undergoing alterations and being considerably extended, the convenience of motor driving was fully appreciated.

Barrow. In 1897 the Naval Construction and Armaments Co. was purchased, and the large works at Barrow-in-Furness were thoroughly reorganised and extended, the number of men employed growing from 5,000 to 10,000 within three years from the time of acquiring the works. The Barrow works presented a very fine opportunity for applying electric power, and during the first year between 50 and 60 steam engines were taken out with over a mile of steam pipes.

It may be mentioned here that the change from steam engines to motors was made without in any way stopping the work. The change was made quickly and without inconvenience—in fact it was half done when the author was asked to state when the alterations were to *commence*, as much stoppage of work was expected.

5. The power-house on the *Shipyard* side contains the following—750 k.w.:—

Five 250 B.H.P. Mirrlees Watson compound single-acting non-condensing engines.

Five 150 k.w. British Thomson Houston shunt-wound, 6-pole, 220-volt generators.

Six 30 ft. × 8 ft. Lancashire boilers, 160 lbs.

One Berryman heater.

Twelve months saw this plant fully loaded, and it was decided to put down a larger plant on the engine works side, as the engine department had already become large users of the current for all their extensions.

6. The *Engine Works Power-house* contains space for five sets, four of which are installed—

Four Belliss triple-expansion engines each 700 B.H.P., 300 r.p.m.

Three 500 k.w. British Thomson Houston Co. 12-pole, 220-volt shunt generators.

One 500 k.w. Vickers, Sons and Maxim 12-pole, 220-volt shunt generator.

One switchboard with 4 generator panels and 32 feeder panels.

Ten Lancashire boilers, 30 ft. by 8 ft., 180 lbs. working pressure (8 in use at present).

Two Green's economisers, each 480 tubes, driven by 2½ H.P. motors.

Stokers—Bennis automatic, driven by a 10 H.P. motor (also drives coal elevator).

Coal Conveyor.—Bennis, driven by a 10 H.P. motor.
Ash Elevator and Motor.—Driven by a 5 H.P. motor.
Four Klein steam-driven sets of air and circulating pumps.
Two Klein cooling towers.
Two Klein jet condensers.

The two power-houses are connected in parallel, a system which is adopted in the other works where there are two or more stations. This plan enables one station to assist the other during temporary heavy loads, and permits of either being shut down at times of light load. Recording wattmeters are fitted in each dynamo circuit, and outputs are recorded on log sheets for the purpose of checking costs.

There are three other works of the Company using electric power, as follows:—

7. *North Kent Works.* 180 H.P. 220 volts.

8. *Wolseley Tool and Motor Car Works.* 350 H.P., 220 volts.

9. *Electric and Ordnance Accessories Company.* 560 H.P., 110 volts. Making a total plant capacity of 1,180 B.H.P. or 786 k.w. for these three works.

The author does not think it necessary to go further into details of the generating plant, as it is all of a type familiar to the members of the Institution and does not call for special description.

Reason for Adopting 220 Volts.

In 1895, when the choice was made, 220 volts represented advanced practice, as incandescent lamps had only been for a short time on the market for that pressure. No doubt a higher pressure would have offered some advantages in the Sheffield and Barrow works on account of the distances, but the difference between 220 and 250 is not really very important. With 440 volts one must give up the idea of using single glow-lamps unless the three-wire system is adopted.

It would be interesting, in the discussion, to hear the views of engineers as to the suitability of three-wire distribution with 440 volts across the outers, taking motors of 5 H.P. and upwards from the 440-volt mains, as well as all crane motors and others of intermittent loading. Small motors with steady loads, as well as arc and glow lamps, would be connected between the middle and outer wires. With careful arrangement the system should do well in large works, and it would have the advantage of giving variable speed-motors double the range they would have on the ordinary two-wire system.

It may be thought curious that shunt generators are used in all cases, as many power-stations have compound-wound generators. In practice the author has found that with a fairly large generating plant shunt generators are perfectly satisfactory, the pressure on the lamps is quite steady. By the use of shunt machines the switchboard gear is slightly simplified. If all the work had to be done again with a full knowledge of the ultimate demand for power, it is probable that the

only differences would be in the direction of raising the voltage of supply to 440, using three-wire distribution, and certainly making use of the larger sizes of plant, each unit being 750 or 1,000 k.w. capacity.

The practice of installing small sets as well as large ones, which is common and justifiable in lighting-stations, does not appear to possess any advantages for heavy works driving, as the loads are fairly uniform and of known duration. If the size of unit is chosen with due regard to the ultimate plant capacity, allowing the standby set to bear a reasonable proportion of the whole—say 20 per cent.—it is far better to have all the units alike, with a full set of interchangeable spare parts.

Cost of Production.

The systematic recording of all costs, properly subdivided, is of the utmost importance. The weekly returns, when properly kept, are sensitive indications of the state of the plant and also of the care shown by the engine and boiler staff. Although the costs as shown in the following tables are not as low as some which have been published recently, they are of interest as representing the actual figures taken from the books of the Works Cost Department. They are not made out by the Electrical Department for show purposes, nor are they the result of a week's test under exceptional conditions. They include Sundays, holidays, and other "unprofitable" times from a station engineer's point of view.

Summary of Generating Costs (One Year).

Power House.	Present Plant Capacity	Annual Output.	Fuel per Ton.	Works Costs per Unit.	Total Cost, per Unit.
	K.W.		s. d.		
(*a*) Sheffield, North	640	2,106,340	9 8½	·579d.	·716d.
(*b*) Sheffield, South	1,325	2,610,620	7 2½	·469d.	·675d.
(*c*) Sheffield, West	750	Not long enough in operation for costs.			
(*d*) Erith	600	1,430,500	20 0	1·1d. (about)	
(*e*) Barrow Shipyard... ...	750	644,500	17 0	1·3d. (about)	
(*f*) „ Engine Works	2,000	3,504,435	11 6	·77d.	·97d.
(*g*) Electric and Ordnance Accessories Co. (Dowson Gas plant)	375	364,000	19 10	·55d.	Fuel and wages only.

Total Output (including smaller works) = 11,000,000 units per annum.

Notes.

(*a*) Fully loaded.

(*b*) Not fully loaded; the plant capacity during the period of test was only 975 k.w.; the fourth set has only been put down recently. This station can easily turn out 4,000,000 units annually.

(*d*) Includes pumping all works' water with steam from these boilers.

(*e*) Comparatively lightly loaded, and includes steam supplied to a hydraulic plant.

(*f*) The building, pipes, condensers, and cooling towers are complete, and the plant capacity was only 1,500 k.w. during the year of test, while the power-house will accommodate 2,500 k.w.

Charging the proper proportion of the final capital cost against the present plant for the year, the interest and depreciation amount to ·2d., making total cost = ·97d. per unit.

(*g*) The works having been recently acquired, further information is not available.

CAPITAL OUTLAY ON PLANT AND BUILDINGS (VARIOUS WORKS).

	£	s.	d.	
Sheffield, North	20	10	0	per killowatt.
Sheffield, South	25	16	0	" "
Erith	22	10	0	" "
Barrow Shipyard	24	3	0	" "
Barrow Engine Works	26	10	0	" "
Electric and Ordnance Company	26	5	0	" "

The most interesting figures are those relating to the Sheffield works, and an analysis of the cost is given below :—

	Power House.	
ITEM.	North.	South.
Coal	·313	·255
Water	·046	·016
Wages and Supervision	·102	·101
Stores	·017	·016
Repairs	·101	·081
Works cost ...	·579d.	·469d.
Taxes	·027	·026
Share of Works Railway, Carting Coal and Ashes, Boiler Insurance, Employer's Compensation, etc.	·004	·004
Interest and Depreciation	·106	·177
Total Cost per Unit	·716d.	·675d.

The difference in the costs is due partly to the variation in the price of coal according to the locality, and partly to the nature of the load factor.

The Sheffield works possess the best load, lasting through the entire day and night (day load, 5,150 amperes; night load, 4,500 amperes). This refers chiefly to such work as steel melting, armour-plate and gun work, which must go on continuously. The other works make less use of night work, although a good deal is done at Barrow and Erith at times.

The amount of standby plant is determined by the number of working hours. In the case of a railway wagon shop for which the author acted as consulting engineer, no spare plant was put down, nine

hours being the usual working day. These hours of working permitted all repairs and repacking of the engine to be done during the stopping-time, and no need of spare plant has ever been felt. The usual practice is to allow 25 per cent. of standby plant when all the sets are installed.

It is interesting to compare the results of the north and south power-houses at the Sheffield works. Both work on exactly similar loads, in fact they are connected to a common network; one is condensing and has economisers in the flue, the other is non-condensing and has exhaust steam feed-heaters. The non-condensing station has sets only half the size of the condensing station, and there is a difference in the cost per unit of about $\frac{1}{10}$d. in favour of the condensing station accounted for in coal and water alone.

Finally, before leaving the subject of generating plant, the author would like to state that his experience of high-speed vertical engines running under the severe conditions of continuous heavy loads has been perfectly satisfactory. The cylinder liners of some of the engines have been carefully gauged after five years' work, and show practically no wear.

Distribution Mains and Wiring.

In almost every case the main cables are overhead, on insulators carried partly by posts and partly by the buildings. A light insulation is used to avoid short-circuits where wires come accidentally into contact, blown by the wind, as well as for the protection of telephone and other bare wires. A few underground cables have been used, but the ground in the steel works is tunnelled by flues carrying hot furnace gas, and it is not, therefore, often found possible to use underground mains. A lead-covered concentric cable, 220 yards in length, carries current to a pumping station at the riverside through a tunnel, which is often filled with water in rainy times. The motors in the pumping station are of 60 B.H.P. capacity.

Motors.

It must be owned that most of the success of electric driving has been due to the great improvements which have recently been made in manufacturing motors. Certainly there are still numbers of the old motors in use which were put down six years or more ago, but if the old smooth-core armatures had not given way to the more robust tramway type of armature, many of the applications of electric driving could not have been made. The motor and starter of six or seven years ago were things to be handled with care, and hardly to be trusted to an ordinary workman to start. Now, Messrs. Vickers have over 1,300 motors in use, all of which are started and controlled by the workmen attached to the machines or cranes, and, in spite of the very rough usage still common in the shops, it is wonderful how well the modern machines take care of themselves.

At the outset a strong effort was made to cut down the number of sizes of motors, and also to secure interchangeability of the armatures

and other parts likely to require replacement. Once decided upon, a type of motor was kept as a standard until a sufficient reason caused it to be superseded. For instance, perhaps twenty or thirty motors of 10 H.P. were ordered, with a spare armature to fit any of them. When these motors were all used, it was considered that one spare armature might fairly be allotted to those twenty or thirty motors, and if a better type of motor of that size were available there was no objection to adopting it, and having a spare armature for the new type.

The following list gives particulars of the standard motors and their speeds :—

B.H.P.	Type.	Speed.
1	Semi-enclosed	1,200
2½	" "	800
5	" "	600
5	Enclosed	600
5	Semi-enclosed	Variable—300 to 900
10	" "	600
10	Enclosed	600
10	Semi-enclosed	Variable—300 to 900
15	" "	600
20	" "	600
25	" "	600
25	" "	Variable—300 to 900
30	" "	500
40	" "	500
50	" "	500
75	" "	400

Of course there are a certain number of other types, on cranes and small portable tools, but the same principle of interchangeability and few types has been a ruling factor throughout.

These speeds are lower than many makers call their standards, but when one considers that in nearly every application the speed has to be reduced to quite a small proportion of the original speed at the point of utilisation, it will be seen that a low initial speed is a great advantage, often counterbalancing the rather higher cost of the motor. No hard and fast rule can be made determining the size of machine which should be driven by a separate motor. At first it was decided to make 5 B.H.P. the smallest motor for a single machine, but many cases arose where it was found advantageous to put a motor of 2 or 3 H.P. on a machine which only worked intermittently.

The use of single motors has proved of great convenience in placing machines, rendering them independent of the line shaft; it also allows a free space for the travelling cranes to work in by dispensing with the network of overhead belting. As regards actual efficiency during working time there is little to choose between line shaft driving and separate motors, although the difference is in favour of the separate motor system unless the smallest motors are used. Considering a line

of ten lathes, each of 18-inch centres, driven in three alternative ways, viz.:—

(1) By one 40 B.H.P. motor and line shaft 110 ft. long.
(2) By ten 5 B.H.P. motors, constant speed, with step cones for varying speed. Belt drives.
(3) By ten 5 B.H.P. motors, variable speed, mounted on the lathe headstocks, and no belts.

The capital outlay and losses at *full load* are set out in the following table:—

	Cost of Driving Arrangements.	Loss in Shafts and Belts.	Loss in Motors.	Total Loss.
(1) 40 H.P. motor. Machines in 2 rows of 5 per row	£410	4 E.H.P.	4 E.H.P.	8 B.H.P.
(2) Ten 5 H.P. motors (constant speed)	£575	2 E.H.P.	7·5 E.H.P.	9 B.H.P.
(3) Ten 5 H.P. motors (300 to 900 speed)	£685	—	7·5 E.H.P.	7·5 B.H.P.

In the case of the 40 H.P. motor there is a fixed loss of about 4 H.P. in shaft and belts, when the shaft is running and no lathes working. With no lathes working in the cases 2 and 3 there is no consumption of energy. With five of the ten lathes working the comparison is as follows:—

	Loss in Shaft and Belts.	Loss in Motors.	Total Loss. B.H.P.
40 H.P. motor	3	3	6
Five 5 H.P. motors, constant speed	1	3·75	4·75
Five 5 H.P. motors, variable speed	—	3·75	3·75

Working conditions would be fairly represented by assuming eight out of ten machines to be in use, the remaining two having tools or work changed or set.

The choice really lies between the 40 H.P. motor and one of the two separate motor systems, and of these two the variable-speed system is certain to be preferred by any one who has had experience of its

convenience. Comparing systems 1 and 3 for working cost under average conditions, the results are approximately as follows:—

Eight lathes working out of ten—
Total loss—System 1 = 7½ B.H.P.
" " 3 = 6 "

One B.H.P. is practically one unit at the switchboard, there is thus a saving of 1½ units per hour, or 1⅛d. per hour at ·75d. per unit. This amounts to 5s. per week of fifty-four hours, and £13 per annum. From this saving must be deducted the interest at 4 per cent. on the difference in the capital outlay, which is equal to £11 per annum, leaving the apparent balance of only £2 per annum in favour of the variable-speed motors.

This saving is the minimum, as the working conditions do not always prevail, and for every hour of overtime work with only one or two lathes working there is a large balance in favour of the small motors. As the load diminishes below half load on the large motor its efficiency falls away rapidly, while the small motors are always working at a high efficiency when working at all. The output of work is largely increased by not requiring belts to be shifted in the latter case.

The above case is not particularly favourable to variable-speed motors; the price per unit is usually above ·75d. in works only running fifty-four hours per week. Working continuously 5½ days per week, the nett saving would be 1⅛d. × 132 = 12s. 4d. per week or £32 per annum, less £11 interest = £21 per annum, plus the large saving due to increased output and reduced power costs for overtime work.

No doubt the first cost prevents many owners of works from adopting separate motor driving, but where money can be raised at a cheap rate of interest there is little doubt that that system is the more economical one where the machines are of sufficient size to justify the use of separate motors. Unfortunately it is a common habit, when electric driving has been decided upon, for the works manager or engineer, with no special knowledge of the subject, to take the settlement of all the details on himself, with the result that many of you must have seen. Electric driving will not necessarily cheapen production in all cases, and unless it is undertaken with some knowledge and a good deal of thought, it may affect the cost of producing work adversely.

The author has had to advise in the case of some works where the conditions appeared to be most favourable to electric driving at first sight. The engine was about 40 years old, the shafts, belts, and general arrangements were as badly planned as could be, and yet, on carefully estimating the cost of conversion and probable saving, there was so small a margin that he advised the retention of the existing plant in the interests of economy. The percentage saving would have been considerable, but the coal bill and other costs were so low that the financial results would have been disappointing. For the same reason, it is only where the conditions are very favourable that electric

driving can replace the older system economically in parts of the country where coal is cheap.

The particular case referred to above was that of a small compact factory, in three stories, covering but a small ground space. The steam pipe was very short, and the losses were chiefly in the shafts and belts. As the machines were many and small, it would have been impossible to dispense with the shafts, and only the main belts from floor to floor would have been saved by motor driving. Had the works consisted of isolated shops instead of floors, the case would have been entirely favourable for electric driving.

The number and horse-power of the motors in the various works of the Vickers Company are stated in the following table, which divides them into three classes, viz. :—

(1) Motors working continuously.
(2) Motors on cranes and hauling gear.
(3) Motors performing auxiliary operations, such as travelling lathe saddles and other occasional work of very short duration.

The average current absorbed by the motors in each case is also stated, and it is a rough indication of the size of generating plant required for dealing with such a load. Of course this figure naturally varies according to the proportion of crane motors to those of steady loading, but it may be of use to engineers when considering new cases of a similar nature.

Total number of motors (all the works) = 1,311.
Total B.H.P. of motors " " = 12,400.

TABLE SHOWING MOTORS INSTALLED AND AVERAGE LOADS.

Works.	Shafting and Machine Motors.		Crane Motors.		Intermittent Load Motors.		B.H.P.	Average current at 220 v.	Amperes per B.H.P. of Motors at 220 v.	Ratio Constant Load Motors to Total H.P.
	No.	B.H.P.	No.	B.H.P.	No.	B.H.P.	Total.			
Sheffield	299	2464	170	2683	174	657	5804	5150	·89	·425
Barrow ...	295	3388	145	1542	—	—	4930	5530	1·125	·690
Erith ...	80	862	33	216	—	—	1078	1100	1·02	·800
Wolseley	14	160	—	—	—	—	160	just	installed	1·00
North Kent	11	122	—	—	—	—	122	220	1·80	1·00
Elec & Ord (110 v.).	90	300	—	—	—	—	300	1500	2·50	1·00

GEARING.

The question of type of gearing is of great interest; few machines lend themselves to direct driving by motors of reasonable speed

without the interposition of a certain amount of gearing. Fans, saws, and some woodworking machines are practically the only cases where high speeds are required. The choice of gearing is not very wide. The types may be divided into the following classes :—

(1) Worm Gear.
(2) Spur Gear with metal wheels.
(3) Spur Gear with metal and raw-hide.
(4) Spur Gear with mortice wheels.
(5) Friction Gear.
(6) Chain Gear.
(7) Belting.

The author has tried all the above, and finds that only spur gear, chain gear and belting are of real use, except in special cases.

Worm Gearing, to be efficient, must be fitted with ball thrusts, run in oil, and must be very well made. It is expensive, but where great speed reduction is required it is useful, especially in such cases as hoists, where the work is occasional and the efficiency of minor importance.

Friction Gear is inefficient and cannot be applied for large powers.

The three classes of *Spur Gear* are all good ; the speed and permissible amount of noise determines which class should be adopted. The author places a limit of about 1,000 feet per minute for metal spur gears, beyond which the noise becomes unpleasant in ordinary machine shops. At this speed, cut gears with well-formed teeth are necessary. Raw-hide and metal can easily be used up to 2,000 feet per minute.

Belting is of course applicable to nearly all cases, the slipping being a positive advantage where heavy shocks and reversals of machines take place.

Chain Gearing has the advantage of silence and positive driving; it is most suitable for short drives. Renold chains from 5 to 80 H.P. are used in the Sheffield and Barrow works, with excellent results. Chain drives are only fit for shop's which are clean and free from dust and grit, unless special steps are taken to case them in well. A common method of line shaft driving is to fix the motor to a column or wall bracket and drive the shaft by a chain, the centres of the shaft and motor being about three or four feet apart. This economises floor space, and a speed reduction of 6 to 1 is easily obtained, as the chain wheel may be considerably smaller than a belt pulley transmitting the same power.

Variable-Speed Motors.

The problem of varying the speed of motors without loss of efficiency has received a good deal of attention during the last few years, and there is now no difficulty in building motors with a range of three to one, or even more, by varying the field excitation. The limiting factor is the highest speed to which it is permissible to go from mechanical considerations, and the range and lowest speed depend on the price to which one is prepared to go. A three to one range appears to be about the most economical one for motors of fair

size, say from 250 to 750 revolutions, or 300 to 900 revolutions for motors from 5 to 30 H.P. Any reduction of speed below about 300 causes the weight and price to rise rapidly.

The author's firm is now building motors which work sparklessly with fixed brushes with a speed variation of three to one, and it is only on account of the difficulty of arranging satisfactory mechanical drives that higher maximum speeds are not used.

An application of variable-speed motors which the author believes to be novel has been recently used in the electrical manufacturing shop of Messrs. Vickers. A portable vertical planer or slotting machine is driven by a 5 B.H.P. motor with a range of speed from 300 to 900, the motor being attached direct to the machine. On the cutting stroke the motor runs at its slowest speed, and at the end of the stroke, the length of which is easily adjusted to suit the work, the motor reverses automatically. As soon as the reversal has occurred a resistance is automatically inserted in the field winding, quickly raising the speed to 900 for the return stroke. At the end of the quick return stroke, immediately before reversal, the field resistance is short-circuited, providing a strong field for reversing in, and the motor reverses and makes its slow cutting stroke, the cycle repeating itself. The insertion and removal of the field resistance necessitates a special form of switch which is provisionally protected and cannot at present be described in detail. The arrangement has been in use for some time successfully, and it is anticipated that it will be of great use in driving many types of reciprocating machines. In actual practice it is found that this method of driving is very economical and possesses advantages over the usual belt reversing drive, as the excess current at reversing can be reduced to a negligible quantity.

There are about 110 variable-speed motors in the Sheffield works driving lathes and gun-boring machines, and they do their work most satisfactorily. They were all built by the electrical department of the Company.

There is a great saving of time in such operations as parting off heavy shafts, the turner being able to follow the work as the diameter diminishes and keep his cutting speed at its maximum without having to shift his belt from step to step.

While the motors for line shaft and machine driving are almost invariably shunt-wound, there are cases where the conditions call for heavy starting currents, and compound motors or pure series motors are used. Such machines as punching and shearing machines, angle and beam cutters, and other shipyard and boiler-shop tools, have heavy flywheels, requiring large currents to accelerate them. The work is done by a temporary fall in speed of the flywheel, and the light-load current does not fall below about half the full-load current. Here series machines are excellent, a constant speed is not required, and there is always sufficient load to keep the speed from reaching a troublesome limit.

Reversing motors do not seem to be in use to the extent that their merits entitle them to, and it is a very common thing to see plate-bending rolls and straighteners driven by a motor belted to a counter-

shaft, which drives the machine by open and crossed belts. The space occupied is considerable, and the belts usually slip a good deal. There is no difficulty whatever in arranging good compact drives with reversing motors driving through spur gearing. In the Barrow Shipyard there are several rolls driven thus, by 45 and 30 H.P. motors. Liquid controllers are used for these, and in the Sheffield works some rolls for bending 3-inch gun shields are driven by 22 H.P. tramway motors with standard tramway controllers.

Some of the most interesting examples of electrically driven machines are described in the following table of tests, and although many of them may be very similar to results published in other papers, the author hopes that, taken in bulk, they may be of use to engineers as a table of reference. The machines are divided into 11 classes as follows:—

1. Lathes and Boring Machines.
2. Planing Machines.
3. Slotting Machines.
4. Shipyard Plate Machines (Punchers, Shears, Countersinks, Angle cutters, Rolls).
5. Drilling Machines.
6. Pumps.
7. Cranes.
8. Saws for Metal.
9. Wood-working Machines.
10. Special Machines.
11. Fans and Blowers.

The method of setting out the tests may seem cumbersome, but unless the conditions are clearly stated and the method of driving described in some detail, the results are of little use.

Class I.—Lathes and Boring Machines.

Machine. *36 in. Centre Lathe. 90 ft. long.*

Drive. By a short belt from rocking countershaft. Motor drives countershaft by steel spur gearing.

Motor. 10 B.H.P. 600 r.p.m. Shunt.

Work. 9·2 in. gun tube. Weight about 5 tons, diameter 20 in. Hard steel, cutting speed 5 ft. per minute.
4 cuts $\frac{3}{16}$ in. × $\frac{3}{16}$ in. traverse = 6·8 B.H.P.
4 cuts $\frac{3}{16}$ in. × $\frac{1}{4}$ in. traverse = 7·5 B.H.P.

Another test on same lathe:—

Work. Mild steel shaft, 11 in. diameter, 16 ft. long.
Cuts $\frac{3}{8}$ in. × $\frac{3}{8}$ in. traverse. Cutting speed 10 ft. per minute.
With no cut Lathe takes 3·1 B.H.P.
With 1 cut " " 4·6 "
With 2 cuts " " 5·5 "
With 3 cuts " " 7·0 "
With 4 cuts " " 9·4 "
Rising after half an hour to 10·5 B.H.P.

A similar 36 in. Lathe driven by 10 B.H.P. variable-speed motor, 250–500 r.p.m. through steel spur gearing :—

Work. 23-ton gun tube, forging hard steel.
Running light = ·6 B.H.P.
4 cuts ⅜ in. × ¼ in. traverse. 10·7 B.H.P.
Cutting speed 5 ft. per minute.

Machine. *40 in. Centre Lathe.*
Drive. Belt from motor to countershaft.
Motor. 10 B.H.P. shunt. 600 r.p.m.
Work. Mild steel shaft 36 ft. long, 18 in. diameter, 24 tons.
4 parting cuts each 1¾ in. wide × ·05 traverse. 9 B.H.P. taken.
Running without cuts, 3·5 B.H.P.

TESTS OF POWER TAKEN BY LATHES USING VICKERS' HIGH-SPEED TOOL STEEL.

Lathe.	Material.	Cutting Speed.	No. of Tools.	Lbs. of Metal per hour.	Cut.	Tra-verse.	B.H.P.	Lbs. of Metal per B.H.P. hour
36″ Centres	Gun Steel	12′ per min.	1	187	·38″	·166″	9	21
,,	,,	21′ ,,	1	280	·38″	·166″	15·4	18·2
,,	,,	32′ ,,	1	360	·26″	·166″	15·4	23·4
,,	,,	12′ ,,	4	460	28″	·166″	19·8	23·2
,,	Gun (very hard)	8′ ,,	4	110	·50″	·143″	15·0	7·33
,,	Gun steel ingot	51′ ,,	1	502	·99″	·05″	25·5	19·7
,,	Gun steel ingot	48′ ,,	1	570	·58″	·10″	33·0	17·3
,,	Marine shaft (32 tons tensile)	50′ ,,	1	480	·50″	·10″	22·0	21·8
40″ Centres	Marine shaft	13·5′ ,,	8	900	·3″	·25″	39	23
30″ ,,	Gun steel	18′ ,,	2	795	·45″	·188″	30	26 5

Note.—Allowing a tool to cut at such a rate that it requires grinding after two hours' work, the weight removed per hour is about 220 lbs. per tool, and the B.H.P. is about 11 per tool. A lathe with four tool posts can therefore absorb over 40 H.P., but as the four tools are not always cutting equally heavily in roughing, most of the lathes used for roughing in the Sheffield works have motors of 30 B.H.P., with overload capacity up to 40 B.H.P.

Twenty lathes of from 30-inch to 40-inch centres are having 30 H.P. motors fitted in place of the former 10 H.P. motors.

Boring Machines.

Machine. *24 in. Centre Gun Boring Lathe.*
Drive. Motor to countershaft spur gear, belt to lathe.
Motor. 5 B.H.P. shunt, 600 r.p.m.
Work. 6 in. gun tube, boring 8 in. hole out of solid, 3 inches per hour. (Ordinary tool steel.)
5·4 B.H.P. 5·7 lbs. steel per B.H.P. hour.

Machine. *Ingot and Tube Boring Machine.*
Drive. Through steel spur gearing.
Motor. 10 B.H.P. shunt, 600 r.p.m.
Work. Boring 9 in. hole from the solid in 27-ton gun forging (which is rotated).
Traverse $2\frac{1}{2}$ in. per hour. (Ordinary tool steel.)
B.H.P. = 5·5. 8·4 lbs. steel per B.H.P. hour.

Another Test :—
Boring 12 in. hole from solid in 15-ton ingot.
Traverse $2\frac{1}{2}$ in. per hour.
B.H.P. = 7·2. 11·25 lbs. steel per B.H.P. hour.

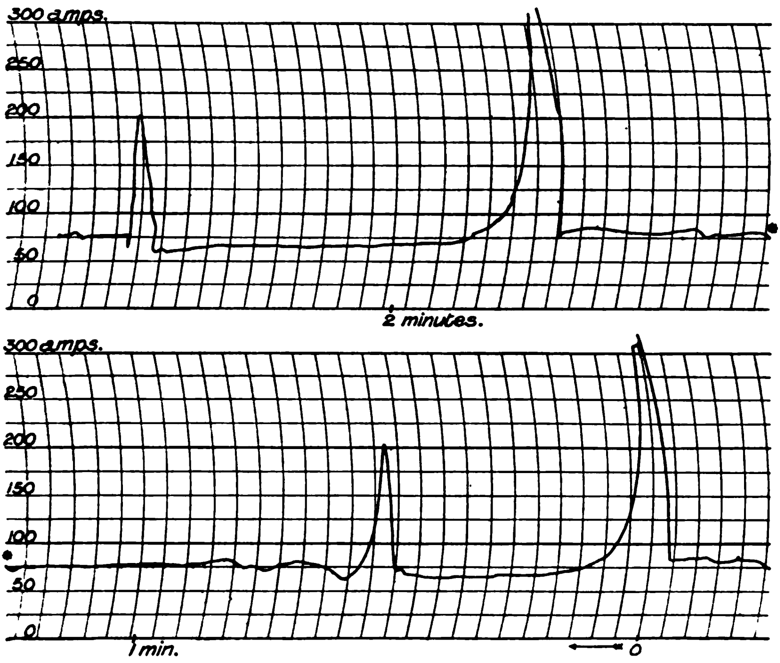

FIG. 1.

Machine. *Double-Barrel Boring Machine for 6 in. Guns.*
Drive. Spur gear and worm gear.
Motor. 10 H.P. Vickers variable speed, shunt, 350–500 r.p.m.
Work. Boring a gun tube from both ends.
Diameter of hole $7\frac{7}{16}$ in. one end, $6\frac{1}{2}$ in. the other end.
Traverse $2\frac{1}{2}$ in. per hour each end. (Ordinary tool steel.)
B.H.P. =8·04. 7·54 lbs. steel per B.H.P. hour.

Machine. *6 in. Gun Boring Machine.*
Drive. Spur and worm gearing.
Motor. 25 B.H.P., variable speed 300 to 900 r.p.m.

Work. Boring $5\frac{1}{16}$ in. diameter hole out of solid gun steel at the rate of 42 in. per hour (21 in. each end) with Vickers' high-speed steel. Power taken = 25·5 B.H.P.

Machine. *12 ft.* × *12 ft.* × *25 ft. 6 in. Planer.* (See Fig. 1.)
Gear. Spur gear and belt reversing.
Motor. 40 B.H.P., shunt, 720 r.p.m.
Work. Parting a 12 in. nickel steel armour plate, 23 tons.
2 tools, each $1\frac{1}{4}$ in. wide, cutting speed 12·5 ft. per minute.
Quick return stroke 30 feet per minute.
Cut and quick return take 17 B.H.P. Reversing takes up to 70 B.H.P.

CLASS II.—PLANING MACHINES.

Machine. *Heavy Armour-plate Planer,* 10 *ft.* 6 *in.* × 10 *ft.* 6 *in.* × 25 *ft.* stroke.
Gear. Belt drive, open and crossed belts (8 in. wide, double).
Motor. 15 B.H.P., 400 r.p.m., shunt-wound.
Work. (1) Running without cuts, 4-ton plate on table.
Cutting stroke, 4 B.H.P.
Reverse slow to fast stroke, 20 B.H.P.
Quick return stroke, 9 B.H.P.
Reverse fast to slow stroke, 12·5 B.H.P.
Extra for each cut $1\frac{1}{4}$ in. wide parting tool on nickel steel plate = 2 B.H.P.
(2) 12 in. nickel steel plate, 30 tons.
Cutting stroke (no cut on), 7 B.H.P.
Reverse to quick stroke, 24 B.H.P.
Quick return, 15 B.H.P.
Reverse to slow stroke, 15 B.H.P.
The cutting speed was 5 ft. per minute. The cuts were on the hard Harveyised surface.
Extra for each $1\frac{1}{4}$ tool = 2 B.H.P.

Machine. *Side-planing Machine for Armour Plates.*
Gear. Open and crossed double 4 in. belts.
Motor. 5 B.H.P., shunt, 600 r.p.m.
Work. 6 in. nickel armour-plate, cutting in both directions.
Running machine without cut, 1·4 B.H.P.
Cuts $\frac{3}{4}$ in. wide parting tool.
(1) Cutting the hard face, 5 ft. per minute, 4 B.H.P.
(2) Cutting below the hard face, 9 ft. per min., 5·5 B.H.P.

Machine. *4 ft. 6 in.* × *4 ft. 6 in.* × *12 ft. stroke Planing Machine.*
Drive. By belt from motor.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Running belt on loose pulley, 3 B.H.P.

Cutting stroke (no cut on) 19·5 ft. per minute, 3 B.H.P.
Reverse, maximum, 25 B.H.P.*
With 30 cwt. steel forging, two tools cutting 19·5 ft. per min., 5 B.H.P.
Reverse to quick return, 25 B.H.P.*
Quick return, 69 ft. per minute, 7 B.H.P.

Machine. *Planer, 5 ft. 6 in. × 5 ft. 6 in. × 12 ft. stroke.*
Drive. Motor on planer drives countershaft direct at 300 to 400 r.p.m. Open and crossed belts to pulleys.
Motor. 10 B.H.P., shunt, speed variable from 300 to 400 r.p.m.
Work. Planing cast-iron motor frames.
Cut $\frac{1}{4}$ in. × $\frac{1}{16}$ in., 16 ft. per minute (2 tools).
Quick return, 43 ft. per minute, 5 B.H.P.
Reversing takes 15 B.H.P.
Cutting takes 4·5 B.H.P

CLASS III.—SLOTTING MACHINES.

Machine. 30 *in. Stroke Slotter.*
Drive. Belt.
Motor. 5 B.H.P., shunt, 600 r.p.m.
Work. Slotting gun breech ring, about 24 in. stroke.
(1) Cut $\frac{1}{4}$ in. × $\frac{3}{64}$ in. traverse, 2 B.H.P.
(2) Roughing cut $\frac{3}{4}$ in. × $\frac{3}{64}$ in. traverse, 4·5 B.H.P.
Quick return stroke, 1 B.H.P.
(3) The heaviest observed current on any work which the machine will do was equal to 6 B.H.P.

Machine. 36 *in. Stroke Slotter.*
Drive. Belt.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Cutting mild steel, $1\frac{1}{4}$ in. × $\frac{1}{16}$ in. traverse, 28 in. stroke.
Cutting, 7 B.H.P.
Reverse to quick return, 9 B.H.P.
Quick return, 5 B.H.P.
Reverse to cut, 7 B.H.P.
9 lbs. of steel per B.H.P. hour.

CLASS IV.—SHIPYARD PLATE MACHINES.

Machine. *Large Plate Rolls,* 30 *in. wide.*
Drive. Main drive by spur gear into two bottom rolls.
Motor. 45 B.H.P., series reversing, 450 r.p.m., enclosed.
Work. Reversing rolls, about 50 B.H.P. (momentary).
Running rolls light, 15 B.H.P.

* After fitting a C.I. disc 33 in. × $2\frac{1}{2}$ in. on the motor as a flywheel, the *reversing H.P. was reduced to* 16. As the motor had a high sparking limit, it was kept on the work; the heavy load was not of sufficient duration to affect the temperature.

Bending 16 ft. × 1¾ in. cold plate—
Reversing rolls up to 80 B.H.P. (momentary).
Running, 25 to 30 B.H.P.
A magnetic brake was fitted to stop the motor quickly. It lifted at 45 amperes.

Lifting Gear for above Rolls. Top Roll, 30 in. diameter.

Gear. Bevel and worm gear, reduction 100 to 1.
Motor. Two 10 B.H.P. series, 600 r.p.m., one each end of roll.
Work. Raising one end, 10 B.H.P.
Raising both ends, 18 B.H.P.
Lowering one end, 8 B.H.P.
Lowering both ends, 15 B.H.P.
Pressing the roll on to a 9 ft. × 1 in. steel plate, 22 B.H.P.
When motors were brought up all standing, the maximum current rose to 160 amperes. No damage done.
Magnetic brakes fitted to each motor to check the rolls with accuracy when lifting and lowering.

Machine. *6 ft. 3 in., Vertical Rolls.*
Drive. Spur gearing.
Motor. 22 B.H.P. tramway motor, 575 r.p.m.
Work. Bending 3 in. nickel steel gun shield to about 24 in. radius, at dull red heat.
Average load, 25 B.H.P.
Maximum observed, 35 B.H.P.
(As the work is intermittent, the above motor is found to be quite strong enough.)
Auxiliary Motor. 5 B.H.P. series, 600 r.p.m., for feeding the rolls in bending. Fully loaded.

Machine. 10 *in. Boiler Shop Rolls* (converted from engine drive).
Drive. Belt to countershaft carrying old engine pulley and open and crossed belts to machine. Speed of rolls 10 r.p.m.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Running open and crossed belts on loose pulleys, 3·5 B.H.P.
Rolling $\frac{9}{16}$ in. cold plate into 19 in. diameter tube 8 ft. 2 in. long, 11 B.H.P.
Reversing. No noticeable increase.

Machine. *Shipyard Rolls—20 ft. 6 in. Rolls.*
Drive. Open and crossed belts to shaft carrying old engine pinion.
Motor. 30 B.H.P., series, 600 r.p.m.
Work. Rolling ⅜ in. plate, 30 in. wide, 9 B.H.P.
Rolling ½ in. plate, 15 in. wide, 12 B.H.P.
Reversing, 32 B.H.P.

Machine. *Plate Straightener ("Mangle").*
Drive. By open and crossed belts.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Running rolls light, 3 B.H.P.
Rolling ¼ in. plate, cold, 42 in. wide, 4 B.H.P.
Rolling $\frac{7}{16}$ in. plate, cold, 48 in. wide, 8 B.H.P.
Reversing, about 10 B.H.P.

Machine. *Small Shearing Machine (used for shearing Rivets).*
Drive. By fibre pinion and cut steel wheel.
Motor. 5 B.H.P., shunt, 600 r.p.m.
Work. Running light, 1·5 B.H.P.
Shearing one ¾ in. rivet at a time, 3 B.H.P.
Shearing three ¾ in. rivets at a time, 4½ B.H.P.

Machine. *Shipyard Punch and Shears.*
Drive. Belt to flywheel from motor in pit. Converted from steam engine drive.
Motor. 5 B.H.P., series, 600 r.p.m.
Work. Punching 1½ in. holes in ¾ in. ship's plate, 6 B.H.P.
Shearing ¾ in. plate, 9 B.H.P.

Machine. *Heavy Punch and Shears (Three-headed Machine).*
Drive. Belt to flywheel from motor on entablature carried by derrick standards. Converted from engine drive.
Motor. 20 B.H.P., series, 600 r.p.m.
Work. 26½ strokes per minute.
Running light, engine still connected, 9 B.H.P.
Running light, engine disconnected, 3·5 B.H.P.
Shearing 1 in. plate, 17 B.H.P., rising to 24 B.H.P. on a long plate.
Punching 1 in. holes in ¾ in. plate, 7 B.H.P.

As not more than two heads are in use at once, the motor is found to be quite large enough.

Machine. *Horizontal Beam Punch and Shears.*
Drive. Belt to flywheel from motor on entablature.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Running light, 30 strokes per minute, 2·5 B.H.P.
Starting current, 13 B.H.P.
Shearing angle bar, 5 in. × 3 in. × ½ in., 5 B.H.P.
Shearing bulb bar, 9 in. × 3½ in. × 1 in., 9 B.H.P.
Shearing angle, 4 in. × 4 in. × ⅝ in., 9 B.H.P.
Shearing angle, 6 in. × 6 in. × ¾ in., 13 B.H.P.
Shearing bar, 6 in. × ½ in., 5 B.H.P.
Shearing angle, 3 in. × 2½ in. × ¾ in., 3 B.H.P.

Machine. *Squeezer for Straightening Bars and Rails.*
Drive. Belt from motor on old engine standard.
Motor. 5 B.H.P., series, 600 r.p.m.
Work. Running light, 2 B.H.P.

Straightening a rail, 2½ B.H.P.
Starting, about 10 B.H.P.
The flywheel is very heavy, weighing over 1 ton.

Machine. *Three Plate Countersinks.*
Drive. Belts from a 40 ft. length of 3 in. shaft. Motor drives shaft by belt.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Running three belts on loose pulleys, 2 B.H.P.
Running three machines light, 3½ B.H.P.
Three 1¾ in. holes countersunk at once in ⅝ in. plates. Speed of countersinks 130 r.p.m., 11 B.H.P.

Machine. *Two Countersinks and one Edge Planer.*
Drive. Belts from 70 ft. of 3 in. shaft, 160 r.p.m.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. All machines on loose pulleys, 3 B.H.P.
Two countersinks working, 8 B.H.P.
Planer alone, ½ in. plate, $\frac{1}{16}$ in. cut, 16 ft. per minute, 10 B.H.P.
Average load, usual conditions, about 14 B.H.P.

Machine. *Scarphing Machine (two Shaper Heads).*
Drive. Belt drive.
Motor. 5 B.H.P., shunt, 600 r.p.m.
Work. ¾ in. ship's plate, both heads working.
Cut, taper from ¾ in. to ⅛ in. deep × $\frac{1}{16}$ in. traverse = 6 B.H.P.

Machine. *Large Edge Planer (25 ft. stroke).*
Drive. Belts, open and crossed.
Motor. 20 B.H.P., shunt, 600 r.p.m.
Work. Planing 1 in. plate, $\frac{1}{16}$ in. cut, 14 ft. per minute = 18 B.H.P. Reversing did not exceed this.

Machine. *Small Edge Planer (12 ft. stroke).*
Drive. Belts, open and crossed.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Planing a ship's plate on the surface.
Cut 2½ in. wide × $\frac{1}{16}$ in. deep, 14 ft. per min. = 15 B.H.P
This is unusually heavy work for this machine; it seldom takes more than 10 B.H.P.

Class V.—Drilling Machines.

Machine. *Portable Drill up to 2 in. Diameter.*
Drive. Spur gear reduction and Stowe flexible shaft.
Motor. 2 B.H.P. Variable speed, 750 to 1,000 r.p.m.
Work. 2 in. hole in mild steel.
Rate of feed, 0·15″ per minute.
Speed of drill, 30 r.p.m. = 1·5 B.H.P.

Class VI.—Pumps.

Machine. *Centrifugal Pump, 18 in. Outlet.*
Drive. Renold chain.
Motor. 70 B.H.P., 600 r.p.m., shunt.
Work. Lift 29 ft. (maximum) 5,500 gallons per minute. Speed, 275 r.p.m. = 67 B.H.P. (maximum lift).

Machine. *Centrifugal Pump, 8 in. Outlet.*
Drive. Direct, by 20 B.H.P. Motor, 800 r.p.m.
Work. 5 tons per minute, 32 ft. head = 23 B.H.P.

Machine. *Centrifugal Pump, 5 in. Outlet (for Condenser Water).*
Drive. Direct, by 4 B.H.P. series motor, 750 r.p.m.
Work. 2 tons per minute against 12 ft. maximum head = 3·25 B.H.P.

Machine. *Vertical Shaft Turbine Pump, for Raising Condensing Water from the River.*
Drive. By cast-iron bevel gear.
Motor. 5 B.H.P. series, 600 r.p.m.
Turbine. Speed, 350 r.p.m.
Work. Raising 6 tons per minute against 10 ft. head (maximum) B.H.P. taken = 5·15 when the head was 5 ft.

Class VII.—Cranes.

As there are 157 cranes of sizes from 1½ to 100 tons, it is quite mpossible to describe many of them. A few of the most important only are described.

The Table below gives the average ratios of H.P. to lifting capacity

Class of Crane.	Motor B.H.P. per Ton Lifting Capacity.		
	Lift.	Long Traverse.	Cross Traverse.
Melting House	1·0	·6	·25
Foundry	·7	·5	·20
Forge	·4	·4	·17
Gun Shop (Heavy Guns), 17 Cranes	·75	·25	·13
Armour Plate Planing Shop		Single Motor—	·5 B.H.P per ton.
Armour Erecting Shop ...	1·1	·375	·2
Light Machine Shops ...	·8	1·2	·4
2 Tons Electric Lifts ...	9·0	Single Motor	

in different shops. The figures are not by any means adhered to in all cases, many cranes of intermediate lifting capacity having motors a size larger or smaller than the average ratio dictates, for the sake of interchangeability. The ratios stated simply show average values which give satisfactory service under the various conditions.

Number of Motors per Crane.—In most cases there are three motors, one to each motion, although some of the earlier rope-driven cranes were converted to electric cranes by attaching one motor to drive the three existing motions. Experience of both types has proved that the cost of upkeep is less with three motors than with one, and the efficiency

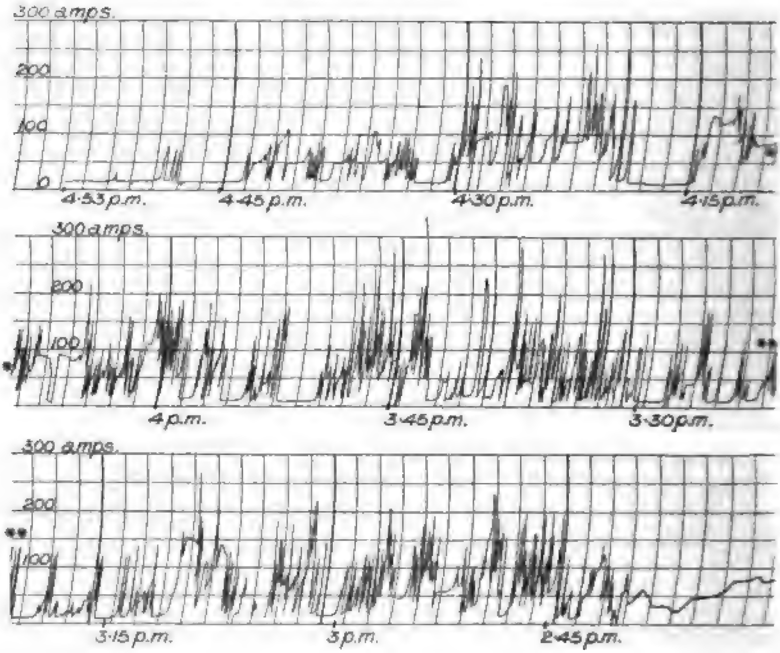

FIG. 2.

is greater. On some of the heaviest cranes five motors are used, there being two crabs, one for light work, to avoid having to lift small weights at the comparatively slow speed limiting the motor of the heavy crab.

In connection with the average current taken by a number of cranes, the diagram (Fig. 2) is of interest. It represents the curve drawn by a recording ammeter in a circuit serving 7 cranes, with 21 motors of a total B.H.P. of 397. This is the largest number of cranes on any single circuit, and the curve only shows to a small extent the tendency of a number of cranes to provide a uniform load. As a matter of fact, although some of the single cranes take 400 or 500 amperes to start them, there is hardly any sudden fluctuation observable

on the main ammeters in the power-house. Fig. 3 shows the record of a single 20-ton 3-motor crane. The average speeds of the different motions are as follows—

	Feet per Minute.		
	Lifting.	Long. Travel.	Cross Travel.
5 Tons Crane	20	300	70
10 " "	15	250	70
20 " "	12	200	60
60 " "	8	150	50

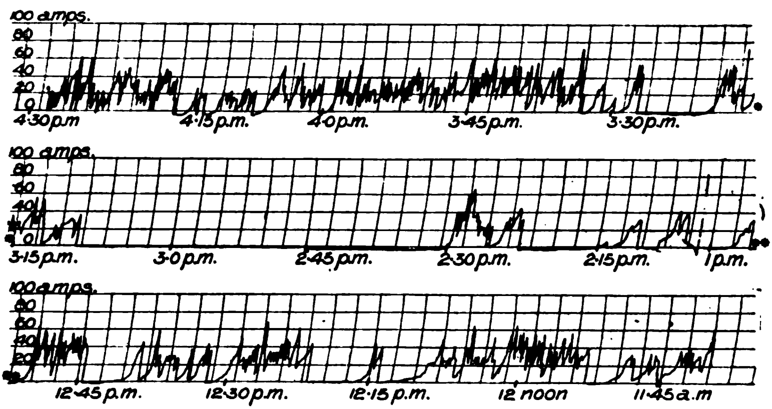

FIG. 3.

The largest crane is a 100-ton crane by the Wellman-Seaver Company of America, in the steel melting house. The span is 46 ft. 6 in., and there are five motors of 260 total B.H.P. in the following units:—

	Motor B.H.P.	Feet per Minute.
Main Crab, Lifting	100	8
Auxiliary Crab, Lifting	50	25
Main Crab, Traverse	25	50
Auxiliary Crab, Cross Traverse ...	5	100
Longitudinal Travel	50	150

Weight of crane and motors = 140 tons.

All motors are tramway type, and all controllers are of the commutator type with magnetic blow-out and iron strip resistances.

Another crane of particular interest is a 60-ton crane in the armour-plate shop, used for dipping the plates in the oil bath. Here it is necessary to lower the hot plate quickly, and accidents have occurred through too quick lowering with the ordinary type of crane bursting the bands of the armature. Any stopping of the plate when half immersed means firing the oil in a tank about 30 ft. deep.

The old 3-motor crane was transferred to another shop and replaced by a 4-motor crane with the following motors :—

Lifting	45 B.H.P.
Travelling	15 „
Cross Traverse	8 „
Pump Motor	4 „

One end of the lifting-rope is wound on a barrel driven by the 45 H.P. motor, the rope then passes over a sheave on the trolley down to the lifting-hook, then up over another sheave on the trolley and along to

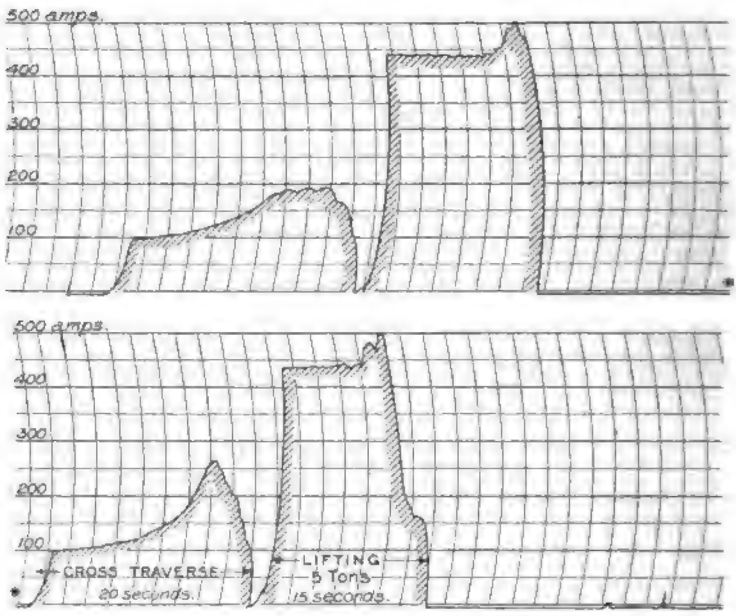

FIG. 4.—Brown Hoisting Co.'s Cantilever Crane.

the end of the crane-girder where it passes several times over sheaves attached to a hydraulic cylinder and ram. Before lifting, the cylinder is pumped full of water, and the ram is forced out to its full extent; lifting is done by the 45 H.P. motor, and lowering is performed as quickly as desired by allowing the water to escape from the cylinder.

Another crane of exceptional interest is that used for the transport of iron ore from the stockyard across the River Don to the railway within the works. The span across the river from track to track is 187 feet, and the overall travel of the trolley is 360 feet, extensions at either end being carried on the cantilever principle.

The three motions for lifting, travelling, and cross-traversing are driven by a series-motor of 85 B.H.P., through clutches; the controllers

are of the tramway type, and the whole is operated by one man in a cab attached to one of the travelling carriages. The height of the trolley rails above water level is 47 feet.

The following readings were taken immediately after erection, when the motions were naturally a little stiff:—

(1)	Travelling		80 feet per minute.
	„	starting ...	75 B.H.P.
	„	running ...	44 „
		(with 5 tons on hook.)	
(2)	Trolley travel		1,000 feet per minute.
	Starting		64 B.H.P.
	Running		32 „
(3)	Hoisting		400 feet per minute.
	Starting		100 B.H.P.
	Running		100 „

The curve (Fig. 4) shows the current taken (at 200 volts) when lifting a weight of 5 tons, transporting it across the river and lowering it into a railway truck. There are four similar cranes at the Barrow Shipyard, two over the building berths, and two in the plate and stockyards. The motors are of the same power, and the arrangements generally are similar except that the overhangs are much longer.

The ship cranes are 320 feet overall, and run on trucks about 730 feet long and 80 feet above the ground, carried on steel gantries. They will lift 15 tons, and the speeds of the respective motions are stated below.

Lifting 15 tons	125 feet per minute.
„ 7½ „	300 „ „
„ ½ ton	700 „ „
Trolley travel	400 to 800 „ „
Crane „	400 to 700 „ „

These cranes are of the greatest service in accelerating the building of ships and placing the armour.

Class VIII.—Metal Saws.

Machine.	*Armour-Plate Sawing Machine.*
Drive.	Cut steel spur gear.
Motor.	5 B.H.P., shunt, 600 r.p.m.
Work.	Sawing 2½ in. thick armour-plate.
	One saw 38 in. diameter × ¾ in. thick.
	Speed of saw teeth 13·5 ft. per minute.
	Rate of cutting, 9 in. per hour.
	Power taken = 3 B.H.P.

Machine.	*Double Armour-Plate Saw.*
Drive.	Belt from motor to machine.

Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Sawing two plates, 2½ in. and 2 in. thick respectively.
Speed of saw teeth, 15·7 ft. per minute.
Rate of cutting plates, 6 in. and 10 in. per hour respectively.
Power taken = 7 B.H.P.

Machine. *Crank Web Sawing Machine.*
Drive. Four reductions from motor to saw by steel spur gear.
Motor. 2½ B.H.P., shunt, 900 r.p.m.
Work. Sawing out web of locomotive crank 13 in. deep.
Two saws in use, each ⅞ in. wide, 47 in. diameter.
Speed of saw teeth = 10 ft. per minute.
Rate of cutting (each saw), 3·6 in. per hour.
Power taken = 2·25 B.H.P.
15 lbs. of steel removed per B.H.P. hour.

Machine. *Band Saw.*
Drive. By Renold chain.
Motor. 3 B.H.P., variable speed, 600 to 900 r.p.m.
Work. Sawing steel ingot, 14 in. deep, saw $\frac{1}{16}$ in. thick.
Speed of saw 132 ft. per minute, feed ⅛ in. per minute = ·90 B.H.P.

Class IX.—Wood-working Machines.

Machine. 35 *in. Circular Saw.*
Drive. Belt from motor to saw, 3 to 1 ratio.
Motor. 15 B.H.P., shunt, 600 r.p.m.
Work. Cutting 10 in. teak about 8 ft. per minute.
Power taken = 14 B.H.P.

Note.—Belt slipping prevented a higher speed of cutting; with a better drive a 20 H.P. motor would be required.

Machine. 24 *in. Circular Saw* (*portable*).
Drive. Direct from motor spindle.
Motor. 4 B.H.P., shunt, 1,500 r.p.m.
Work. Sawing 6 in. beech 4 ft. per minute = 4 B.H.P.
Sawing 2 in. white pine 10 ft. per minute = 2·75 B.H.P.
Saw running light = ·55 B.H.P.

Machine. *Band Saw* (*Driving-wheels* 36 in.). *Saw* ½ *in. wide.*
Drive. By Renold chain. (Saw speed 3,670 ft. per minute.)
Motor. 2 B.H.P., shunt, 1,000 r.p.m.
Work. Sawing 3½ in. Kauri pine = 1·43 B.H.P.
Sawing 9¾ in. Kauri pine = 2·8 B.H.P.
Sawing 7½ in. yellow pine = 1·63 B.H.P.

Machine. *24 in. Circular Saw.*
Drive. Belt, speed of saw 1,000 r.p.m.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Cutting 5 in. ash, about 10 ft. per minute.
Power taken = 6 B.H.P.

Machine. *Sawmill Circular Saw* (*to take* 60 *in. diameter Saw*).
Drive. Belt, speed of saw 750 r.p.m.
Motor. 30 B.H.P., shunt, 600 r.p.m.
Work. Sawing damp pitch pine 12 ft. per minute, thickness from 10 to 17 in. (average 14 in.).

Power taken { Maximum, 36 B.H.P. / Minimum, 21 B.H.P. / Mean, 26 B.H.P.

Machine. *Grating Saw.*
Drive. Belt.
Motor. 10 B.H.B., shunt, 600 r.p.m.
Work. Cutting 4 grooves 1⅞ in. wide × ¾ in. deep in teak.
Speed of cutting, 2 ft. per minute.
Running light, 2½ B.H.P.
Grooving, 10 B.H.P.

The drive is a bad one, with jockey pulleys for the belts.

Machine. *Wood Planing Machines* (36 *in. wide*).
Drive. Belt.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Planer running light, 2½ B.H.P.
$\frac{3}{16}$ in. cut off 27 in. wide pine 14 ft. per min. = 8 B.H.P.
$\frac{5}{16}$ in. cut off 12½ in. wide teak 14 ft. per min. = 6 B.H.P.
½ in. cut off 22½ in. wide teak 14 in. per min. = 7 B.H.P.

Machine. *Wood Moulding Machine.*
Drive. Belt.
Motor. 10 B.H.P., shunt, 600 r.p.m.
Work. Cutting teak about 5 in. square on three sides and ploughing fourth side, moulding passing through 13 ft. per minute = 10·5 B.H.P.

Machine. *Wood Planing Machine* (24 *in. wide*).
Drive. Belt.
Motor. 5 B.H.P., shunt, 600 r.p.m.
Works. Planer speed, 2,200 r.p.m.
Planing 16½ in. pine ⅛ in. cut, 14·5 ft. per min. = 3·25 B.H.P.
Planing 16½ in. pine $\frac{1}{32}$ in. cut, 14·5 ft. per min. = 2·5 B.H.P.
Planing 14 in. pine ⅛ in. cut, 14·5 ft. per min. = 3 B.H.P.

Class X.—Special Machines.

Wellman Charging Machine for Steel Furnaces.

This machine consists of a carriage running alongside the furnaces on rails 12 feet gauge, having the following motions :—

(1) Longitudinal motion on the rails, 25 H.P. tramway motor.
(2) Cross traverse of the crab or charging platform, driven by a 25 H.P. tramway motor. This crab carries the operator and all the controllers, with the two other motors.
(3) Raising the porter bar which lifts the charge of metal in special tubs, 25 H.P. tramway motor.
(4) Turning gear for turning the bar and tubs over, to empty the charge into furnace, 5 H.P. enclosed motor. All motors drive through steel cut gears.

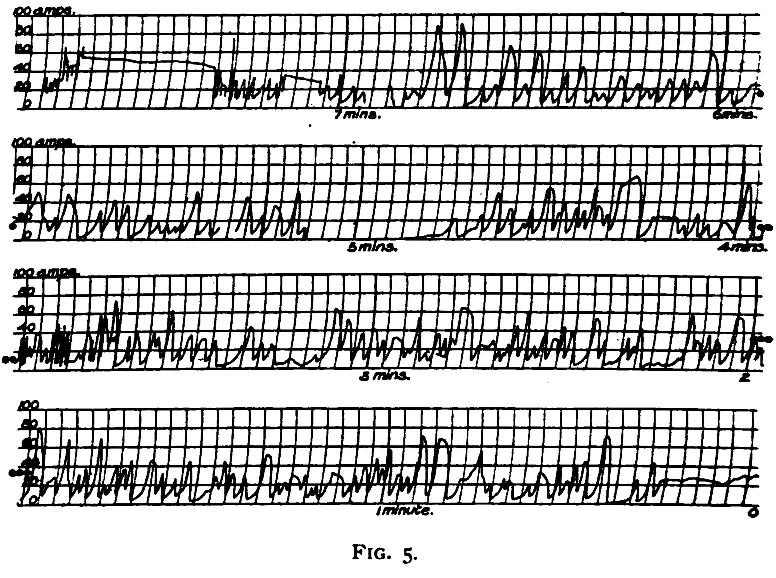

Fig. 5.

The method of working is as follows :—The operator runs the charger along until opposite the furnace door. He then runs the bar forward and lowers it into the slot in the end of tub, which is placed ready on a trolley with others, making the complete charge. The bar is lifted, and when high enough it is run forward into the furnace and turned over, discharging the metal into the furnace. The bar is then withdrawn, and the next tub is emptied in the same way. Two chargers are in use, one on each stage of the melting house.

Power, charging tubs each containing 3 tons, average = 7 B.H.P.
Maximum observed ... ... 40 B.H.P.

It is interesting to compare the cost of charging a 40-ton Siemens furnace by the Wellman charger with the cost of charging by manual labour. Under the former conditions of hand-charging it was necessary to have four highly paid men per furnace, whose earning depended on the tonnage of output; also there were additional helpers kept to give occasional assistance in handling heavy pieces of scrap. The time taken to charge 40 tons was four hours. Now two men are employed in place of four, and the same operation is performed in half an hour, or one-eighth of the former time. (For recording ammeter diagrams, see Fig. 5.)

The output is naturally increased very largely. One man, taken from the ranks of the labourers, made a skilful operator on the Wellman charger with a few days' training, and he attends to six furnaces. The furnace men are relieved of much of the laborious part of their duties, and are at liberty to give better attention to the more skilful part of their work. Also, in the hot part of the year the output is the same as in cool weather, while formerly, with hand-charging, a reduced output was accepted as a natural consequence of hot weather.

Summing up the advantages, we have a reduction in the wage costs of melting of 50 per cent., with an increase in the output of 25 per cent., and the life of the furnaces is considerably extended, consequently repairs are lighter.

The 40-ton charge by the Wellman charging machine takes three Board of trade units at 0·75d. = 2¼d. for power.

	Hand Charging.	Electric Charging.
Capacity of furnace	40 tons	40 tons
Time taken	4 hours	½ hour
Men engaged per furnace	4 + occasional help	2 + ⅛th of the operators' time
Wages per ton	2s. 8d.	1s. 3d.
Electric power	—	2¼d.
Charges per furnace per week ...	9	12

Trepanning Machine. (*Two Trepanning Bars.*)

For boring ingots and gun tubes, leaving a solid core. The bar revolves.

Drive. Spur gearing.
Motor. 15 B.H.P. variable-speed shunt motor, 250–500 r.p.m.
Work. Boring two 6 in. "B" tubes in one piece.
The end of each bar carries 8 tools. (Ordinary tool steel).
Diameter of hole = 9⅜ in., feed 3 in. per hour each bar = 12·4 B.H.P.
Pump for washing out boring driven by a 5 B.H.P. motor.

Another Test, with Vickers High-Speed Tool Steel.

Machine. Similar to the above, but with only one bar.
Motor. 25 B.H.P., variable speed, 300 to 900 r.p.m.
Work. Boring a 14" hole in steel ingot.
Rate of feed, 10½" per hour.
Power taken = 22 B.H.P.

A similar machine (single bar only) trepanning a 21⅜ in. hole in a steel ingot takes 10·9 B.H.P.
Feed = 2¼ in. per hour. (Ordinary tool steel).

Hauling Crab for Furnaces.

A fixed crab, driven by a 5 B.H.P. motor through spur gear, hauls the car carrying armour plates into and out of the furnace by endless chain engaging in sprocket wheels.
Six-wheeled car, carrying 36 tons of plates hauled at the rate of 30 ft. per minute.
Mean power taken = 5 B.H.P.
Maximum „ = 5·25 B.H.P.

Manganese Crusher.

Belt driven from 10 B.H.P., shunt motor, 600 r.p.m.
Running light = 2·5 B.H.P.
Crushing = 9 B.H.P.

Brick Crusher.

Driven by belt from 10 B.H.P. motor, 600 r.p.m. (shunt).
Work. Crushing old bricks and furnace linings for concrete.
Running light = 1·75 B.H.P.
Crushing = 9·5 B.H.P.

Mortar Mills.

(*a*) With driven rolls and fixed tray.
Belt driven from 10 B.H.P. shunt motor, 600 r.p.m.
With tray full of mortar = 12·5 B.H.P.
(*b*) With fixed rolls and driven tray.
Belt driven as (*a*)
With tray full = 9 B.H.P.

Power Hammer, 5 cwt. size.

Vertical hammer with pneumatic cushioning.
Belt driven from 10 B.H.P., shunt motor, 600 r.p.m.
Work. Hammering out wedges for shipyard use, about 6 in. × 8 in., 1 in. thick tapered to nothing.
Hammer striking = 4·75 B.H.P.
Cushioning = 9 to 10 B.H.P.

Note.—A series motor would be better for the work, about 5 B.H.P. It would drop its speed when cushioning, and not take more than about 6 or 7 B.H.P.

Stern Tube Boring Machine.

Starboard tube of H.M.S. *Hogue.*

8 in. diameter bar driven by a worm-wheel and worm, which is driven by a 10 B.H.P. shunt motor, 600 r.p.m., through chain gear and bevel wheels.

Speed of bar, 1·36 r.p.m.

Diameter of hole bored, 26¼ in.

Cutting speed of tools, 9·5 ft. per minute.

Running bar light = 2 B.H.P.

Four tools cutting $\frac{3}{16}$ in. = 10·1 B.H.P.

Armour-Plate Grinders.

There are seven of these machines, each consisting of a long bed on which travels a saddle carrying the grindstone and motor. The motor spindle is extended through a heavy bearing, and carries the chuck into which segments of grindstone are wedged. The speed of motor and grindstones is 400 r.p.m. The motors are of two sizes, 20 B.H.P. and 40 B.H.P., with good overload capacity. The work consists of facing up the edges of armour plates, which to a certain depth are too hard to be machined in a planer. The thickness of plate varies from 2 inches to 12 inches, and the power taken varies from 20 to 60 B.H.P. It is very easy to overload the motors, a slight movement of the feed-wheel presses the grindstone hard against the work, and the current sometimes rises to the equivalent of 80 B.H.P. Heavy fuses are found better than overload release starters, as they are not too sensitive, and by becoming red-hot warn the grinder to ease his cut.

Class XI.—Fans and Blowers.

Steel Foundry Converter Blowers. (Roots.)

Capacity of converter, 2 tons.

Blower direct driven by 75 B.H.P., shunt motor, 500 r.p.m.

Pressure in Converter.	B.H.P.
1·5 lbs.	40
1·75 ,, ...	45·5
2·0 ,, ...	48·25
2·25 ,, ...	53·5
2·5 ,, ...	61·5

Iron Foundry Cupola Blowers. (Roots.)

Charge melted per hour, 8 tons (maximum possible, 9 tons).

Blower driven direct by 75 B.H.P. shunt motor, 500 r.p.m.

Pressure in Cupola.	B.H.P.
Running light	23
14 ozs.	70
15 ,, ...	73

Iron Foundry Cupola Blowers. (Roots.)

Charge melted per hour, 3 tons (maximum possible, 4 tons).
Blower belt-driven by 40 B.H.P. shunt motor, 500 r.p.m.

Pressure in Cupola.	B.H.P.
9 ozs.	34
9½ „	35·5
10 „	37

Steel Foundry Cupola Fan. (Sturtevant.)

Charge melted per hour, 2 tons (maximum possible, 4½ tons).
Belt driven by 20 B.H.P. shunt motor, 600 r.p.m.

Starting	16 B.H.P.
Running light	11 „
Blowing	12 „

Fan for Smiths' Fires.

1,400 revolutions per minute, belt driven from motor 5 B.H.P. 600 r.p.m.
Work—9 fires.
Load—average 5 to 5·5 B.H.P.

48 *in. Fan with* 20 *in.* × 20 *in. Outlet.*

Belt driven at 1,000 r.p.m. by a 10 B.H.P. shunt motor, 600 r.p.m.
Work—23 smiths' fires and air blast for chemical laboratory = 8·5 B.H.P.

Roots Blower—No. 2 "1900" Pattern.

Driven by belt from 10 B.H.P. shunt motor, 600 r.p.m.
Work—8 fires + heavy lead melting-pot.
Speed of blower = 190 r.p.m.
= 6·4 B.H.P.

Portable Air Compressor (for Working Pneumatic Chippers).

Size of compressor, 4 cylinders 10 in. diameter × 6 in. stroke.
Drive—Spur gear.
Motor—15 B.H.P., shunt, 350 r.p.m.
Air pressure—70 lbs. per sq. inch.
Work—6 chipping tools or 3 drills.
Power = 15·3 B.H.P.

Portable Painting and Lime-washing Machine.

Works two paint sprays.
Motor—2½ B.H.P., shunt, 1,200 r.p.m.
Speed of compressor—102 r.p.m.
Gear—Worm, single reduction.
Air pressure—10 lbs.
Power = 2·6 B.H.P.

LINE SHAFT TESTS.

Speed on all Shafts about 120 revolutions per minute.

No. of Shaft.	Shaft. Length.	Shaft. Dia.	No. of Machines.	Class of Work turned out.	Rows of Machines.	Average Size of Machine.	B.H.P. per 100 feet of Shaft.
		inch.					
1	330	3½	13	Large Engine Work	1	7 Drills, about 4½ in. holes ; 3 Wall Planers, 7 ft. to 18 ft. stroke	5·35
2	155	3½	30	General Engine Work ...	5	11 Lathes, 8 in. to 12 in. centres ; 5 Planers, 6 in. to 12 in. stroke ; 2 Slotters, 4 in. to 5 in. stroke, etc.	16·65*
3	240	3¼	17	" "	5	6 Drills, 3 in. diameter ; 6 Lathes, 12 in. centres, etc.	7·17
4	155	3½	45	Small Engine Work	6	6 Shapers, 16 in. to 24 in. stroke ; 7 Milling Machines, 3 in. cutters ; 9 Drills, 3 in. diameter, etc. ; 11 Screwing Machines, ⅝ in. to 6 in. bolts	13·16
5	265	3¼	38	General Engine Work ...	5	39 Lathes, 6 in. to 12 in. centres	7·28
6	200	3¼	36	" " "	5	7 Slotters, 12 in. to 24 in. stroke ; rest small drills, etc.	7·0
7	290	3¼	68	Brass Engine Work	5	46 Lathes, 8 in. to 30 in. ; 8 Drills, 3 in. diameter ; rest small machines	7·69
8	130	3	30	Gun Mounting Work	3	24 Lathes, 8 in. to 14 in. centres ; 4 Automatic Machines, ⅝ in. to 2½ in. bore ...	10·0
9	130	3	71	" " "	5	25 Lathes, 8 in. to 12 in. centres ; 33 Milling Machines up to 11½ in. cutters	16·5*
10	20	3	10	" " "	2	All Capstan Lathes, ⅝ in. to 2½ in. bore	5·0*
11	200	3	45	" " "	3	41 Lathes, 8 in. to 25 in. centres ; rest small machines	10·75
12	200	3	43	" " Fittings ...	5	17 Slotters, 3 in. to 16 in. stroke ; 14 Planers, 3 ft. 6 in. to 12 ft. stroke ; 5 Boring 3 in. spindles	9·9
13	200	3	30	" " "	2	8 Radial Drills, 2 in. diameter ; 6 Wheel Cutters to 20 in. stroke	10·5
14	55	3	4	" " "	2	Planers, 8 ft. to 12 ft. stroke	31·3*
15	140	3	36	" " "	5	30 Lathes, 6 in. to 22 in. centres ; rest small machines	12·7
16	200	3	33	" " "	3	6 Planers, 6 ft. mean stroke ; 6 2 ft. Stroke Shapers ; 6 Lathes, mean 15 in. centres	11.6
17	200	3	23	" " "	3	15 Lathes, 8 in. to 15 in. centres ; 7 Boring, 3 in. spindles	6·65
18	180	3	74	" " "	4	37 Lathes, mean 10 in. centres ; 10 Drills, 2 in. diameter ; rest medium Slotters and Millers	9·56
19	100	3	15	Grinding and Polishing ...	2	7 Emery Wheels, to 14 in. diameter ; 4 5 ft. Grindstones	10·7
20	100	3¼	24	Pattern Shop (Engne)	3	5 Saws, 24 in. ; 4 Planers, 12 in. to 26 in. ; 11 Lathes, 14 in. centres	15·5*
21	220	3¼	8	Ordnance Plate Work... ...	2	4 2 in. Drills ; rest small machines and slotters	4·41*
22	200	3¼	8	" " "	2	Band Saws, Drill, Punch and Shears, Fan, etc.	4·5*
23	130	3	8	" and Boiler Work	1	6 Drills, ⅜ in. to 2½ in. ; 2 Band Saws	4·6*
24	220	2¼	21	Boiler Work	2	8 Screwing, ¼ in. to 5 in. diameter ; 3 Planers, 5 ft. to 15 ft. stroke ; punches, etc.	9·18
25	245	3½	32	Shells	3	All 12 in. to 16 in. Lathes	10·8*
26	80	3½	26	"	3	26 12 in. Lathes	19·4*
27	150	3½	19	"	4	19 10 in. to 16 in. Lathes	9·6
28	150	3½	22	"	2	22 4½ in. to 17 in. Lathes	8·5
29	360	3	63	Ships' Fittings	7	19 Lathes, 15 in. centres ; 10 Drills, 2 in. diameter ; 7 Screwing and Tapping, 2 in. diameter ; 9 medium size Planers, Slotters and Millers	5·6

* Special work not to be considered as ordinary cases. Average of the remainder = 9·1 B.H.P. per 100 feet of shafting.
The author has used 10 B.H.P. per 100 feet in most cases with good results.

The following tables stating the brake H.P. of motors and number of watts consumed per 1,000 feet of shop area may be of use in forming an idea of the probable size of plant required to drive works of a similar nature.

The figures dealing with plant installed do not vary with the state of trade, busy or slack, as do the figures relating to the current consumed per B.H.P. installed, which are also stated in tabular form. It should be noted that in all cases the figures of current per B.H.P. of motors relate to times of normal trade, and a margin should be allowed to cover the possible requirements during times of extra pressure.

B.H.P. of Motors Installed per 1,000 Square Feet of Shop Area.

Sheffield.	North Gun Shop (Heavy Guns, 6 in. to 12 in.) ...	12·8
	South „ („ „) ...	13·4
	East „ (Gallery over alternate bays, 4·7 in. Guns)	12·0
	Armour Plate Planing Shop	15·4
Barrow.	Shipyard Platers' Shed	4·3
	Woodworking (Joiners and Blockmakers)	3·9
	Engine Department Machine Shop	4·4
	Gun Mountings and small work...	4·3
Erith.	6 in. Gun Mounting and Carriage Department (Gallery over alternate bays)	7·45
	Gun Turnery	3·4
	Woodworking Shop (two stories)	6·5
Wolseley Motor Car Company Ltd.	(all small power machines) ...	1·72

Average Current and Watts (at 220 Volts) taken per B.H.P. of Motors Installed.

		Current.		Watts.
Sheffield.	North Gun Shop	1·2	...	264
	South Gun Shop (average of 5 circuits)	1·36	...	299
	East Gun Shop	1·02	...	224
	Railway Axle, etc., Turnery	1·27	...	279
	Cranes in Gun Shops (eight 60-ton cranes on the circuit)	0·5	...	110
Barrow.	Shipyard Platers' Shed	1·05	...	231
	„ Woodworking Shop ...	1·63	...	358
	Engine Department Machine Shop ...	2·06	...	453
	Gun Mounting and small work bays...	1·76	...	392
Erith.	Whole Works (Guns and Gun Mountings small)	1·15	...	253
North Kent.	Field Gun Carriages, etc	1·8	...	396

	Current.		Watts.
Electric and Ordnance Accessories Company, Ltd. (at 110 volts)	5·0	...	550
The current and watts required at 220 volts to give 1 B.H.P. with an average efficiency of 80 per cent. (allowing for motors working slightly under full load) are ...	4·24	...	932

Total Number of Arc and Incandescent Lamps.

	Arc Lamps.	16 c.p. Incandescent.
Sheffield	558	3,500
Barrow	720	4,000
Erith	400	3,500
North Kent	60	400
Wolseley	80	750
Electric and Ordnance	48	900
	1,866	13,050

Total Number and H.P. of Cranes—Electrically Worked.

	No. of Cranes.		B.H.P. of Motors.		No. of Motors.
Sheffield	89	...	2,683	...	170
Barrow	57	...	1,542	...	145
Erith	11	...	216	...	33
	157		4,441		348

Number of 500-Watt Arc Lamps and Kilowatts per 1,000 Square Feet Shop Area.

		Killowatts.		Number.
Sheffield.	North Gun Shop	·448	...	·90
	South Gun Shop	·401	...	·80
	East Gun Shop	·360	...	·72
	Armour Plate Planing Shop	·320	...	·64
	Marine Crank Turnery	·390	...	·78
	Railway Crank and Small Machine Shop...	·250	...	·50
	Iron Foundry	·234	...	·47
	Steel Melting House	·257	...	·51
	Forge	·320	...	·64
	Repairing Shop	·330	...	·66
	Boiler Shop	·356	...	·71
Barrow.	Shipyard Platers' Shed	·310	...	·62
	Woodworking Shop	·275	...	·55
	Engine Department Machine Shop ...	·375	...	·75
	Boiler Shop	·35	...	·70
	Iron Foundry	·21	...	·42

		Killowatts.	Number.
	Steel Foundry ...	·25	·50
	Gun Mountings and small work	·45	·9
Erith.	6 in. Gun Mounting and Carriage Department*	·70	1·4
	Gun Turnery* ...	·68	1·37
	Mechanism and Shell Department*	·68	1·36
	Field Carriage Erecting Shop	·46	·92
Wolseley Tool and Motor Car Co., Ltd. ...		·376	·755

Average Figures.

Heavy machine shops (average height of lamps = 35 ft.) = 400 watts per 1,000 sq. ft. of floor area.

Light work (average height of lamps = 16 ft.) = 375 watts per 1,000 sq. ft. of floor area.

Foundries and steel melting = 240 watts per 1,000 sq. ft. of floor area.

Forge, about 350 watts per 1,000 sq. ft.

These figures vary considerably with the amount of reflection which the walls provide and the possibility of keeping the walls clean.

Although a great deal might be written on the subject of starting gear, switchboards, types of arc lamps, fuses *versus* circuit breakers and many other points all of importance to those interested in the use of motors, the author feels that this paper is sufficiently long without reference to most of them. It would be interesting to hear some experiences of engineers with circuit breakers fitted in such power installations as those described in this paper.

The author has a preference for starters without automatic overload release, and has had to do away with the overload release on a number of starters which were continually giving trouble by switching off when overloaded momentarily. The time-constant of a fuse is a very strong point in its favour, as it will carry a motor over a heavy load of short duration which would at once open the automatic. Also, a fuse's sensitiveness is not affected by vibration, as is the case with most of the automatic overload arrangements. If automatic circuit breakers are fitted on the generator panels, they should also be fitted to feeder panels and to all motors, as the presence of even a small fuse may cause a very large generator to come off load before the fuse has time to melt.

Saving due to Electric Driving.

As the available figures under this head have been published frequently, it will be as well to keep entirely to results obtained by the Vickers Company. The difficulty of stating the saving in terms of simple comparison is very great. When a concern takes up electric driving in earnest, it usually finds that many operations become possible

* An attempt was made here to light entirely by arc lamps, but for the fine machining and fitting incandescent lamps are found necessary.

which were not possible before; consequently new machinery is ordered.

The author does not know a single instance where the conditions of working were the same before and after conversion of works to electric driving.

At Barrow, as already stated, an extension of the shipyard, approximately equal to 50 per cent. increase in the power taken, marched hand in hand with the conversion to motor driving. Also, electric lighting had been largely extended. *The actual result was a saving of half the coal bill, with an increase of over 50 per cent. in output.* In no other instance is it possible to express so direct a comparison.

Where boilers have been relieved of a part of their load through motor driving, the steam set at liberty has been used for other purposes, such as working additional hammers, presses, or other hydraulic plant.

It is disappointing to find that the saving, which is so thoroughly evident to those who use electric driving, cannot be more clearly stated. It is only by considering such cases as the charging machine, where much labour is dispensed with, that an idea can be formed of the magnitude of the saving in works where there are many instances of a similar kind.

In the armour-plate planing shop, now driven by three engines developing over 600 B.H.P., motors are being installed. There will be a saving of six engine drivers (one to each engine on day and night shift), against which there will only be a proportion of the wages of one engine driver in the power-house to be charged. In this shop, which has six cranes of 60 tons lifting capacity, recently converted to electric driving by fitting six single motors in place of 5,200 feet of ropes, a saving of £180 per annum has been effected under the head of rope renewals alone. A very large saving is also made by cutting out the constant loss due to keeping the mile of rope running, and the rate of handling the heavy weights has been doubled. Formerly the repairs to the rope pulleys and running gear formed a very heavy item.

The number of stand-by men in works dealing with heavy weights can be greatly reduced by the judicious use of motors. A few years ago it was usual to keep a gang of men to do such odd jobs as opening furnace doors, and on the large furnaces six men were required to raise some of the heavy doors. Now this operation is performed by a 1½ H.P. motor, and only as many men are employed as can be kept fairly busy.

The author thinks that the future applications of motor driving will be largely in the direction of doing all the rough, heavy work, which is now left to labourers through the shortsighted policy of many employers who will not see that the outlay on motors is soon recovered. A man can do work which a motor cannot, and he should be set free to do that work. As a machine he is not very efficient. The spectacle of six ordinary men pulling on the fall of a rope in as many different directions proves this fact.

The author wishes to express his indebtedness to Messrs. Vickers, Sons & Maxim, Ltd., for their kindness in allowing him a free hand in

publishing the figures in this paper, and also to the following gentlemen for assistance in taking the various tests:—

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ELECTRIC DRIVING IN MACHINE SHOPS.

By A. B. CHATWOOD, B.Sc., Member.

The subject of electric driving has of late years received considerable attention, but there seems to be a great deal of misapprehension in the public mind as to the attitude adopted by electrical engineers in the matter. The author has frequently been told by managers and principals of works that they would wait until electrical engineers had come to some conclusion as to which was the best system and the best method.

Discussions have taken place in this room and elsewhere as to whether direct or alternating current was the more suitable for tool driving, as to whether the final solution of the problem would be one motor per tool or one motor per line shaft, and so on. Whatever value such discussions may have in the abstract, the author is of opinion that in each particular case of machine tool driving electrical engineers would have substantially the same views, and he therefore proposes to leave all discussion of abstract points alone, and to ask the attention of members to three particular cases, out of those which have come closely under his own observation, and to the conclusions to which they lead.

There are, however, a few general questions to which attention may very well be drawn at this point.

Wherever possible, it is desirable to employ direct rather than alternating current, as speed control is of extreme importance with regard to some classes of engineering tools.

The system and voltage to be employed should be such that the installation may either permanently or temporarily be connected to the town mains.

Where, for any reason, a qualified electrician cannot be maintained on the staff, the installation should involve only apparatus which is well understood in the district, so that help or advice can always be readily obtained.

As a general rule it will, the author thinks, be wise to group tools together for driving purposes to a very large extent, but at the same

time to drive certain classes of tools individually. The average number of tools per motor is difficult to arrive at, but in engineering shops doing partly standard and partly odd work of medium weight, the best number will probably work out at from two to four.

The particular cases which it is proposed to submit are those of two

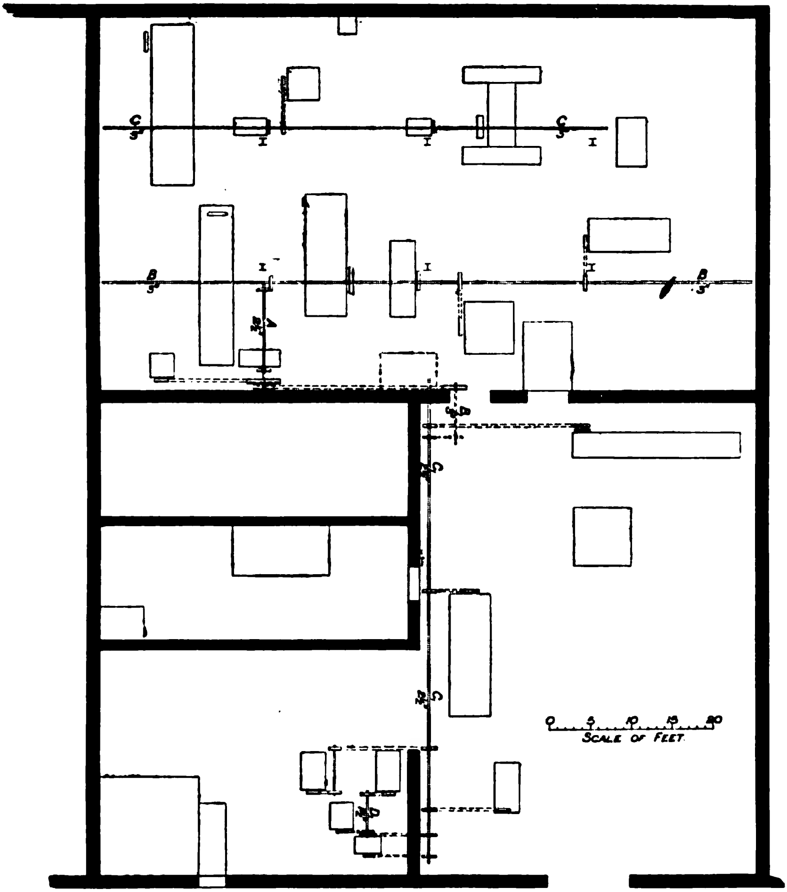


FIG. 1.

old and one new works, all of small size. Plans of all three are shown.

In Bolton, where these shops are situated, direct current is supplied on a three-wire system at 460 and 230 volts, and motors may, under certain circumstances, be hired from the Corporation at 10 per cent.

per annum on the cost of motor, starting switch and fixing, the price of energy being as follows :—

First 500 units per quarter...	2·25d. per unit.
Second " "	1·35d. "
Further consumption	1·00d. "

The author proposes to take these terms for interest and depreciation, and these prices for current, as a basis for the estimates in the present paper.

Case I.

Until May, 1901, the shop shown in Fig. 1 was driven by a Robey portable made at a very early date, and by a small single-cylinder horizontal with vertical boiler placed in the smithy.

At this time the engines were entirely worn out, and in fact for some years previously the repair bill had been enormous, so that it was decided to adopt electric driving, and a 20 B.H.P. motor was installed in the position shown on plan. The shop has since been driven by this motor, with results which are entirely satisfactory except as regards cost and occasional stoppage.

The actual mean load, including shafting, was 15 H.P., and the cost of steam driving somewhat as follows. Owing to the fact that no proper cost books are kept in this works, these figures may be one or two per cent. wrong either way :—

	£	s.	d.
Wages	72	16	0
Coal...	213	7	6
Water	10	6	0
Ash removal	6	0	0
Oil	15	0	0
Repairs	61	0	0
	£378	9	6

for a year of about 2,800 working hours, or about £434 for a year of 3,194 hours. These figures are exclusive of interest or depreciation.

The cost of the single motor drive, at the present rates for current is £186 7s. 2d., as follows :—

	£	s.	d.
10 per cent. on motor, etc.	18	5	0
Cleaning	1	10	0
Brushes	1	16	0
Current	164	16	2
	£186	7	2

The consumption for six months being as follows :—

Date.	Total Units.	Max. Current.	Hours of Running.
June 19 to July 37	2,668	31 amps.	268·5
August 22	3,140	32 „	249·5
September 20 ...	3,123	36 „	274
October 18 ...	3,119	36 „	295·5
November 20 ...	3,170	35 „	249·5
December 20 ...	3,182	32·5 „	269
	18,402		1,597

Mean consumption, 11·52 units per hour = 15·44 E.H.P.
Max. „ „ „ = 22·2 „

Measurements of the current required to drive the shafting alone, including belts and loose pulleys, gave as mean figures :—

9·72 units per hour .... 12·9 E.H.P.

We have therefore in this case—

Useful load ... ... 2·54 E.H.P.
Waste load ... ... 12·9 „

even if we assume, which is certainly not true, that the shafting, etc. absorbs the same amount of power when loaded as when unloaded.

You will notice that the motor drives a cross-shaft A, which in its turn drives at one end a line shaft B, and at the other end an intermediate B′; each of these drives a second shaft C C′, and each of these again drives machine counter-shafts or in some cases another intermediate D′.

This arrangement is not such as would be put up to-day by any self-respecting engineer, but it is typical of a very large class of works which have grown little by little, and in which a machine and a piece of shafting have been tacked on from time to time; sometimes the machine being put in an awkward position for the convenience of the drive, and sometimes the drive being awkward for the sake of the machine.

Case II.

At the present time the shop shown in Fig. 2 is driven by a single-cylinder condensing beam engine of 6 ft. stroke and 25 in. diameter cylinder. Some time ago I had the pleasure of reporting on the electric driving of this shop. The particulars of the loads are as follows :—

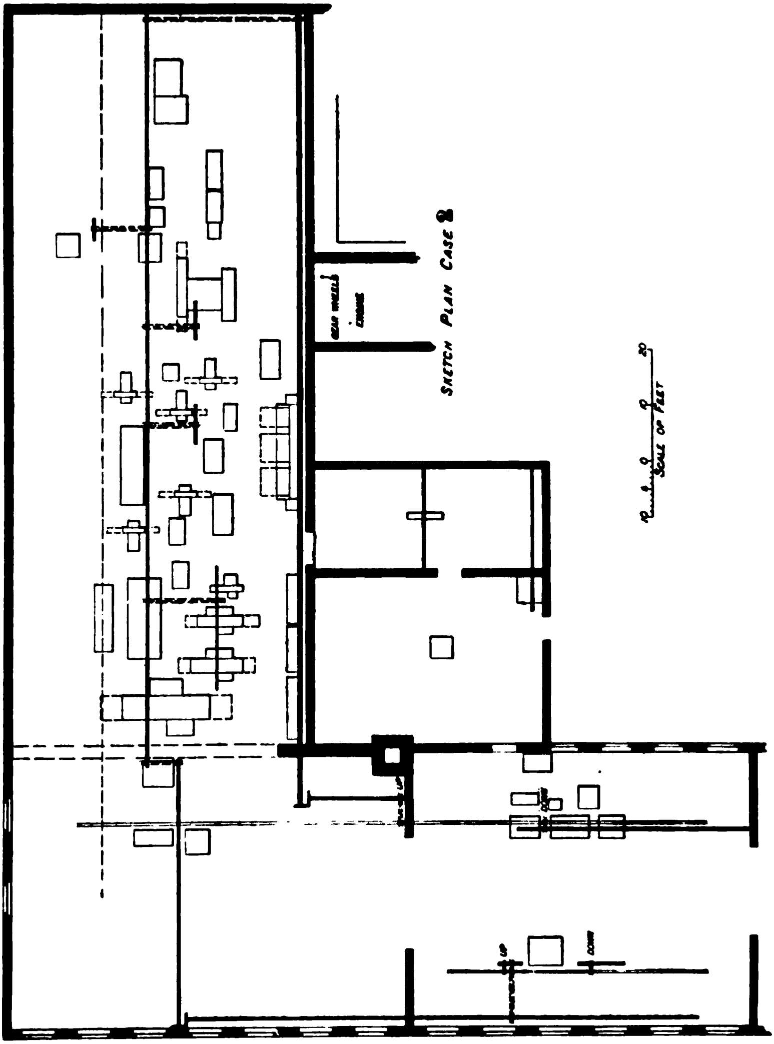


FIG. 2.

Ground-floor Shafting shown solid. Countershafts omitted.
First-floor Shafting shown in outline.
Drives from Shaft to Shaft shown thus -

Mean load	26·6	I.H.P.
Max. "	34–40	"
Engine and shafting friction	22	"
Mean useful load	4·6	"

with the same assumption as before with regard to the power absorbed by loaded shafting.

The coal bill was about £430 per annum, and the total engine costs something like £600, or about £22 per I.H.P. per annum, exclusive of rent, rates, taxes, insurance, interest and depreciation.

Observations were made over some weeks in order to determine the actual intermittency of the tools, with the following results :—

Motor Groups. See page 979.	Class of Machine or Group.	Max. B.H.P. required for Group.	Per cent. of time Group Shaft would run.
1	Plate stretching rolls	6	20
1	Saws...	3	40
1	Drilling machines	$1\frac{1}{2}$	45
1	Milling and slotting machines ...	6	70
1	" " " ...	6	90
1	Small planing machines	6	60
1	" " " special ...	4	60
1	Large " "	6	70
2	Lathes	$1\frac{3}{4}$	50
1	Sheet metal machines	6	14
1	" "	4	36
1	Brass-finishing machines... ...	$\frac{3}{4}$	40
1	Odd brass machines	$\frac{3}{4}$	10
1	Small special lathes	$\frac{3}{4}$	15
1	Polishing laps and brushes ...	4	50
	Drilling machine	$\frac{3}{4}$	60
	" "	$\frac{1}{2}$	50
	Small machines	4	60

The shafting load estimated from an empirical formula, taking into account diameter, length, speed, number of bearings, and number and width of belts, is—

Diameter.	Length.	B.H.P. hours per 3,000 hours.
Inches.	Feet.	
3	135	11,880
3	4·1260	1,260
3	4	1,449
2	22·5	1,530
4	140	18,770
2	22	2,220
2·25	152	4,860
2	222	7,290
		49,250 ≡ 16·4 B.H.P.

a figure which agrees very closely with what one would expect from the indications of the engine.

Taking the shafting load at this figure, and the useful load at the I.H.P. given by the engine, viz., 4·6 H.P., the cost of driving by a single 40 H.P. motor works out at £264 12s. 6d.

	£	s.	d.
10 per cent. on installation	28	0	0
Brushes and cleaning	5	10	0
Current	231	2	6
	£264	12	6

As a matter of fact the drive is being divided over four motors; with what object the author fails to understand, since almost the whole of the shafting is to be driven and no one of the advantages of electric driving is to be secured.

The cost of driving in this way will be greater than that shown by the single-motor arrangement. The estimate being—

	£	s.	d.
10 per cent. on installation	40	0	0
Brushes and cleaning	11	16	0
Current	239	17	6
	£271	13	6

Case III.

The shop here taken as an example (see Fig. 3), unlike those already given, has only been erected a few months, and it had already been decided to drive with current from the Corporation mains; yet in spite of this, the same want of intelligent appreciation of the conditions of the problem are shown.

The works, as will be seen from the plans, consist of two shops one over the other, and a moulding shop. The lower shop contains a small planing machine, slotting machine, shaper, drilling machine, grindstone, and several lathes, one only of which is in fairly constant use.

The business carried on is chiefly that of brass finishers, although all sorts of repairs are done.

In the lower shop it is rare for more than one or two tools to be working at one time, and more often than not only one lathe is in use.

The lower shop, of which we are at present speaking, is driven by a 5 H.P. motor, driving by belt on to a short shaft and thence by belt on to the line-shaft running the length of the shop. The shafting is of steel, and is run in self-adjusting bearings. It has been most carefully installed, and absorbs little power; with seven belts to counter-shafts, including the driving of the loose pulleys this amounted to 1·05 B.H.P. The motor, however, although by a well-known firm, absorbed 2·65 E.H.P., running entirely light at the time the experiments were made; this has since been reduced to 2·47 E.H.P. by an alteration of the maker's adjustment of the brushes. The result is still not what ought to be expected by a very long way.

The upper shop contains several small lathes and other small tools,

and it may be taken that three or four tools are as a rule in operation: there are also a set of polishing brushes which run a small part only of their time, and are driven independently by a separate motor.

The main drive in this shop is by a 6 H.P. motor belt connected to a line-shaft.

This motor when driving only the shaft, belts, and loose pulleys absorbs 2·47 E.H.P.

The author has had observations made as to the time which the motors ran: during the period of observation the polishing motor was entirely idle, that in the lower shop ran 22·75 hours per week of 53 hours, the top shop motor running full time.

This gives us a consumption of 160 units for driving shafting; the meter readings gave a total consumption of 174 units during the 53 hours: thus the energy actually used usefully was 14 units, equivalent to a mean useful load of ·36 E.H.P., or about 8 per cent. of the total.

The annual cost on the assumption that the conditions obtaining during the period of observation are maintained during the year will be—

	£	s.	d.
10 per cent. on installation	12	0	0
Current	56	0	10
	£68	0	10

These figures are exclusive of the cost of running the polishing brushes and a small motor recently erected in the moulding shop.

As the improvement in the efficiency of the 5 H.P. motor is directly due to the measurements taken by the author for this paper, it has not been considered in the above figures, since there is no doubt that it would under ordinary circumstances not have been made.*

Probably there is no problem in the everyday practice of engineering which involves so many factors that can only be ascertained by tedious observation in each case, or where this work is so amply rewarded. Experience is no doubt of very great value, but if any one, however experienced, shirks the trouble of making the observations which have been referred to, the results which he will achieve will fall far short of success.

In the early part of this paper certain general lines were laid down, but it will be found in practice that those conditions are frequently incompatible, and the engineer, as in so many other cases, must make a compromise.

It is seldom that all the advantages of the electric drive can be secured in any particular instance, but with care those most essential to any particular class of work may be obtained without too much complication or loss of financial efficiency.

The possible advantages are :—

1. Reduction of waste load.
2. Positions of machines independent of shafting.
3. Speed of individual machines or groups independent.

* Since this paper was written the makers have been communicated with, and at once offered to replace the motor by a thoroughly efficient one.

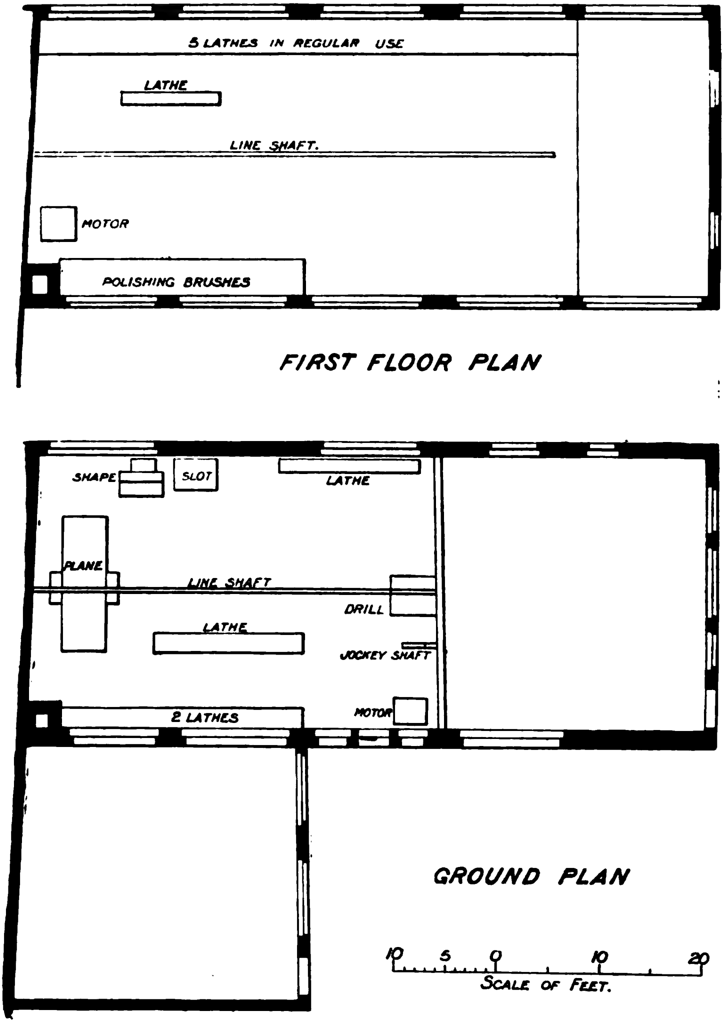

5 LATHES IN REGULAR USE
LATHE
LINE SHAFT.
MOTOR
POLISHING BRUSHES
FIRST FLOOR PLAN
SHAPE
SLOT
LATHE
PLANE
LINE SHAFT
DRILL
LATHE
JOCKEY SHAFT
MOTOR
2 LATHES
GROUND PLAN
10 5 0 10 20
SCALE OF FEET.

FIG. 3.

4. Facility for using portable tools or magnetic chucks.
5. Convenience on occasional overtime.
6. The very partial nature of a breakdown and rapidity of repair.
7. Advantages connected with travelling cranes.
8. Absence of strains in roofs and consequent cheapness of construction.
9. Facility with which power measurements may be made.

The importance which attaches to the reduction of waste load depends largely on what is in the particular shop the original source of power. If current is generated by the use of steam engines on the premises, the saving made by reducing waste load is not at all proportionate to the reduction of the load, as a large part of the cost of generation is due to charges which do not increase in proportion to the load: when, however, current is obtained from an outside source at a practically level rate, this reduction becomes of very great importance.

In being able to place his machines so that they get the best light, and so that as little as possible need be wasted in getting work to or from them, the works manager is in a position to demand the maximum both as regards quantity and quality from his men; and he can see at a glance whether or not machines are being kept in that state of cleanliness which is essential if good work is to be done and if machines are to depreciate little.

The advantages due to the control of the speed of individual machines, both in improving the quality of the work and in increasing the quantity turned out, have not been fully appreciated up to the present; speaking as a practical turner who has had experience of both systems of driving, the author is in a position to say that not only can better work be done but a very great deal more of it on a lathe fitted with a separate motor and a shunt regulating resistance. It is perhaps somewhat rash to estimate the extra output under this heading, but on lathes and planing machines which are not doing repetition work an increase of anything between 20 per cent. and 40 per cent. is usually obtained.

There are two ways in which portable tools may be of very important use: the first when the piece to be machined is of great weight in proportion to the amount of machining to be done on it; and the second when several parts of the piece may be machined simultaneously so that time may be saved.

It is not necessary to speak of the advantages pointed out as Nos. 5, 6, 7, 8 above, as these are either sufficiently well known or are obvious.

It may be pointed out that the possibility of the easy, rapid, and accurate measurement of power which is afforded by electric driving is valuable to the works manager, firstly, because the friction load of a machine is a very reliable indication of the condition of the machine, both as regards its cleanliness and its adjustments; and secondly, because the current consumption as given by a meter shows very clearly whether or not the machine is being worked up to its full capacity or not.

The smallest size of motor which it is ordinarily desirable to employ depends to a large extent on "the taste and fancy" of the engineer; the voltage of supply, however, seems to fix the limit in ordinary cases: the author does not hesitate with a pressure of 200–250 volts to employ motors as small as 1 H.P., and where any great advantage is to be secured thereby, motors of ¼ H.P. It must not, of course, be lost sight of that small motors are less efficient than larger sizes, and that therefore they should only be used where the saving or convenience which can be secured by them outweighs their disadvantages and leaves a large margin of benefit.

The general arrangements as to the number of motors used with which the author is acquainted are:—

1. One motor per works: This replacing of a steam or other engine by an electromotor is, to say the least of it, foolish, as a gas, oil, or steam engine would always give a more economical and equally satisfactory drive.

2. One motor per tool: This arrangement is, as a rule, not the best, as although the cost of the current is reduced very greatly, it is at the expense of interest and depreciation, and it is difficult to imagine an engineering shop where all the tools would be benefited by speed control other than that obtained by cones, etc., or where many tools at any rate are not employed on standard work which enables them to be grouped without loss of efficiency.

3. One motor per line-shaft: This arrangement leads to a certain amount of economy in large works generating their own current, but is decidedly bad where current is purchased at an approximately level rate, as the substitution of oil or gas engines would give a still more economical drive. In either case the advantages peculiar to electric driving are not secured.

4. Mixed arrangement developed from No. 3: In this arrangement one motor per shaft is employed as far as possible without involving long lengths of idle shafting, and a few tools may have separate drives on account of their inaccessibility.

5. Mixed arrangement developed from No. 2: This arrangement, which appears to the author to be the only reasonable one, may be described as one in which each tool having a large percentage of idle time, or which would benefit by a variable-speed control more delicate than that given by the usual mechanical means, has its own motor, and the remainder are grouped, not in any hard and fast way as so many tools per motor, but in larger and smaller groups in such a way that the sum of the interest, depreciation, attendance, repairs and current cost shall be a minimum.

Probably the best way of arriving at the arrangement last described is to pick out those machines which require separate motors in order to secure variable speed, then those which are idle for a large percentage of their time, as it will very likely be possible to group some of these without loss; the remainder of the tools will very probably fall into convenient groups, but if not, their grouping merely involves the calculation of the cost of driving for two or three arrangements.

In grouping it should always be borne in mind that it is often

possible to combine tools to form a group so that the shaft driving the group need only run a proportion of the working hours of the shop. Sometimes one man has a group of machines in his charge of which only one or two run at any moment : a group is thus formed naturally, and may be driven by a motor too small to drive all the machines of the group at once.

There is no doubt that the more the drive is split, the greater will be the total H.P. of the motors required, and so the capital cost, for the help given by the inertia of the shafting, etc., to reversing machines and to those liable to sudden variations of load, is reduced, and the

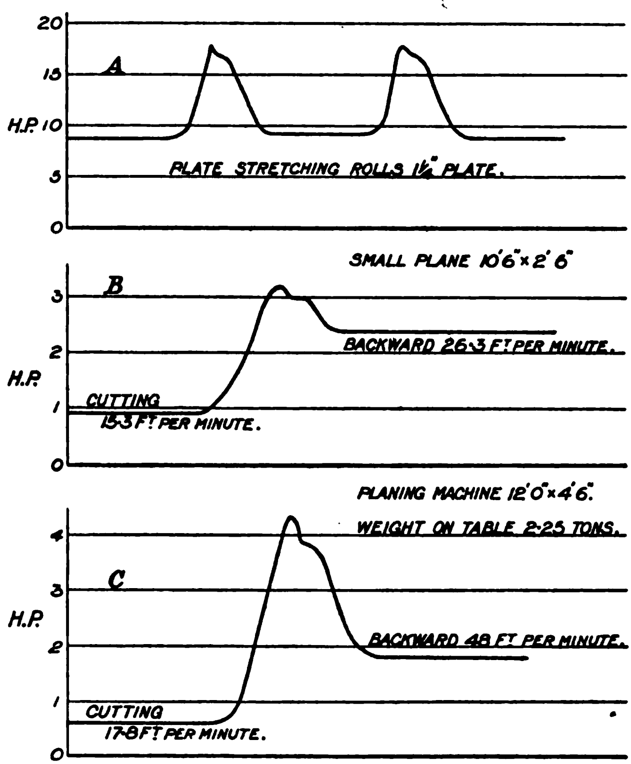


FIG. 4.

fact that a large number of machines having a variable load never synchronise is also neglected.

The total power of motors required with a divided drive such as has just been indicated will of course vary very greatly in different shops, probably as much as from twice to five times the maximum useful load of an engine driving the same shop.

The power absorbed by particular machines can only be ascertained by actual measurement, the power stated by tool makers being some-

times many hundred per cent. wrong. The few powers given below have been measured by the author on tools in actual work under ordinary shop conditions:—

12 ft. × 4 ft. 6 in. planing machine...	Diagram C. (Fig. 4).
Radial drill, holes to 1¼ in.	¾ H.P.
6 ft. × 30 in. planing machine ...	2·65 H.P. in reversing.
10 ft. 6 in. × 30 in. planing machine	Diagram B. (Fig. 4).
Lathe 5½ in.	Up to ·34 H.P., cutting heavy screw.
Lathe 9 in.	·5 H.P. chasing thread on 2½ in. gas-pipe.
Drilling machine, holes to ¾ in. ...	½ H.P.
Plate stretching rolls	Diagram A. (Fig. 4).

The connection between the tool and the motor is at present receiving a good deal of attention, especially at the hands of American tool builders, and large numbers of tools are being built with a motor as

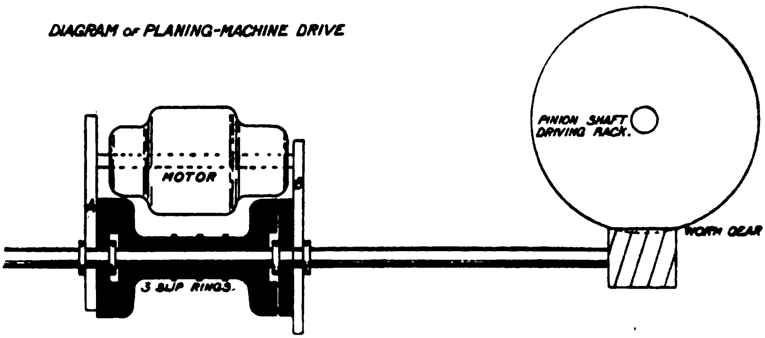


Fig. 5.

The magnetic clutch (solid black) is double-ended and slides on the worm shaft with a float key. In the position shown, the train of gears A is connected to the shaft by the clutch, which is in contact with the left-hand armature. The gear train contains an idler—on the current being passed (by the machine tappets) through the other end of the clutch, the latter slides into contact with the armature attached to gear train B.

a part of the construction. But in dealing with old shops, the connection whether to group shafts or to individual tools has to be provided; more often than not without any serious stoppage of the work: in these cases a belt connection to the group shaft, or to the existing countershaft of the machine, will as a rule be found the most convenient, though a raw-hide pinion and a spur wheel or worm gearing can sometimes be employed and are to be preferred.

There are, however, two classes of machine to which special connections should be fitted, namely, machines which reverse periodically and have large inertia, such as planing machines; and machines of very great inertia which absorb a very large power in starting, yet take comparatively little power in running.

A most ingenious arrangement for driving the former class of machines is already on the market, and the author believes is working perfectly satisfactorily, the only objection to its adoption being that the price is extremely high and is certainly not warranted by the cost of manufacture. A diagram of this appliance is shown in Fig. 5.

The second class of machines which should have special attachment is represented by the grindstone used in many works for removing scale from bars, dressing of rivets, and for other purposes; these stones vary in size, but are usually about 7 feet diameter when new. Such a stone absorbs, with the friction of its bearings, from 2½ to 4 H.P., and occasionally for short periods as much as 5 H.P. after it gets up speed, so that a motor of 4 H.P. is amply sufficient to drive it, but it requires one of at least 15 H.P., even when a few series turns are provided, to start it if both have to start together; and if the motor is allowed to get up speed and the stone then coupled by anything approaching a rigid connection, the motor, even if of 15 H.P., is extremely likely to be injured, as it will be overloaded to an enormous extent.

To meet these difficulties and to provide for a constant peripheral speed in spite of the wear of the stone, as well as for a low speed of about 50 linear feet per minute when turning up, the author has proposed a two-speed motor with a small controller and a shunt regulator driving the stone through a belt, and the use of a magnetic coupling in the shaft which carries the stone, or, if possible, in the motor shaft between the motor and the pulley. The current supplying the clutch passes through a rheostat, so that the power transmitted to the stone is under control.

The method of operating this apparatus is extremely simple; the controller is turned to one or other of its two positions according to the diameter of the stone, and the motor switch pulled over slowly just as in starting a motor, but after the motor has acquired its speed the switch is carried on, cutting out resistance in the clutch circuit and so gradually transmitting more and more power to the stone. The advantage of such an arrangement is that the stone can safely be started by a motor no larger than is necessary to drive it, and no excessive current is called for. There is, of course, the advantage also that the stone can be driven at the best peripheral speed irrespective of its diameter.

The above arrangements have been described at some length and illustrated, not entirely on account of any merit which they possess, but because the solution of every such problem is a help in the solution of other problems, and many difficulties in the electric driving of machine shops have still to be met and overcome.

It may be remembered that a small flywheel on the motor shaft, and a few series turns on the field, are frequently a great help in dealing with a load such as a planing machine.

Returning now very briefly to the three cases of which particulars have been given, and planning out the installations on the lines which have been sketched, we shall see that very appreciable savings can be effected, and all the advantages due to the electric drive secured.

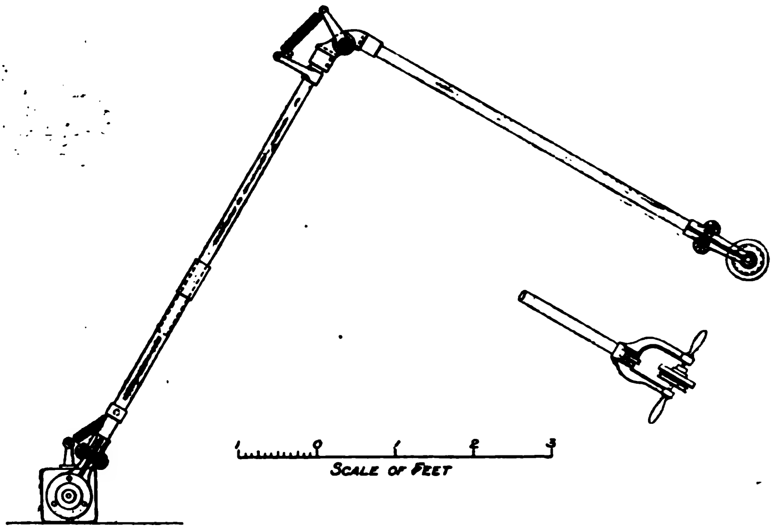


FIG. 6.—Portable Electric Grinder, for dressing seams and rows of rivets in plate-work, Motor on floor driving wheel by twisted leather belt inside tubes.

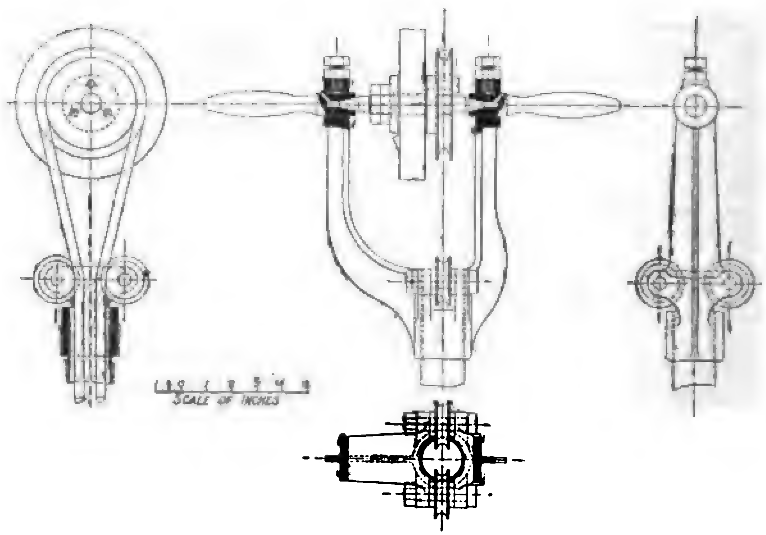


FIG. 7.—Portable Electric Grinder—Details of Head.

Case I.

This case does not lend itself very well to much grouping, those which appear to be advisable being a small group on the lower floor and one on the upper. These would consist of five tools each. The installation would then require fourteen motors ranging in size from $1\frac{1}{2}$ to $7\frac{1}{2}$ H.P., and averaging 2·8 H.P.

The cost of running, based on the same period as that already given, would be—

	£	s.	d.
10 per cent. on installation	34	0	0
Cleaning	7	10	0
Brushes	6	0	0
Current	44	3	10
	£91	13	10

as compared with £186 7s. 2d. with the single-motor arrangement.

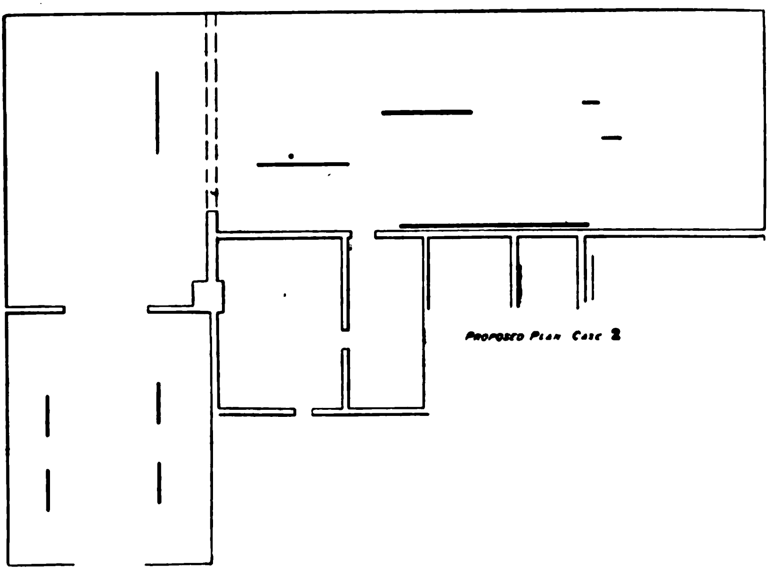


Fig. 8.—All Shafting shown solid.

Case II.

In this case individual speed control can be obtained in every case where it is of very great value, and all awkward drives avoided without the use of a large number of motors; at the same time the dead load can be reduced to the equivalent of 3·1 H.P.

The number of motors would in this case be eighteen, ranging from 1¼ to 6 H.P., the grouping being indicated in the table on page 969.

The cost of the installation would be £700, and the running costs on the basis previously taken.

	£	s.	d.
10 per cent. on installation	70	0	0
Cleaning and brushes	26	0	0
Current	95	7	8
	£191	7	8

as compared with £264 12s. 6d. with the single motor.

Case III.

By dividing the shaft in the upper shop into two, and adding separate motors for the planing machine and the principal lathe in the lower shop, the average dead load could be reduced to 1·86 H.P.

The current consumption per 53 hours would be reduced from 174 to 85 units, of which 16·5 per cent. would be usefully employed.

The running costs for the year would now become—

	£	s.	d.
10 per cent. on installation	19	4	0
Current	29	3	4
	£48	7	4

as compared with £68 0s. 10d.

It is not at all an easy matter to institute any general comparison between the costs of steam and electric driving, but it is possible to suggest certain approximate formulæ which may be of use in arriving at a rough approximation.

The cost of steam driving depends chiefly on the size of the plant and on the ratio which the mean load bears to the maximum, and may be expressed by—

$$A + Bp + Cr,$$

where A B C are constants expressed in £ per annum;
- p is the maximum I.H.P. of the engines;
- r is the mean I.H.P. taken over the year.
- A represents wages in looking after boilers, engines, shafting, and belts.
- B is interest, depreciation, rent, repairs.
- C is coal, oil, and stores.

The following values have been obtained in a few cases :—

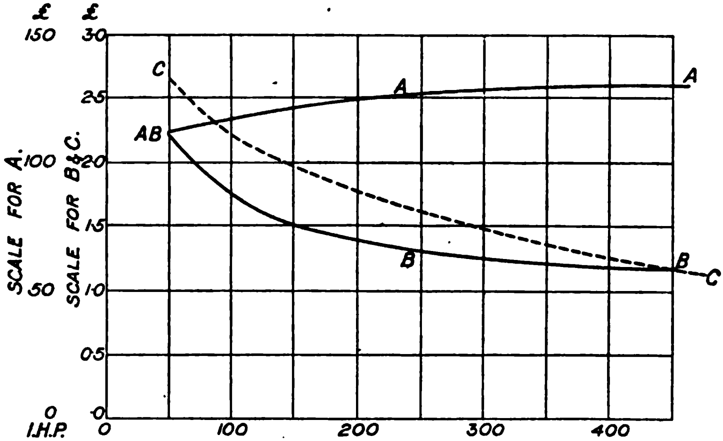


FIG. 9.—Annual Cost of Steam Power. Value of Constants.

In an engineering shop of reasonable size, it is to be remembered that the maximum load is always large compared with the mean.

Taking the case of an engine of 125 I.H.P., we get from the formula and the "constant" curves already given the following curve giving the relation between the ratio maximum mean load and the annual cost.

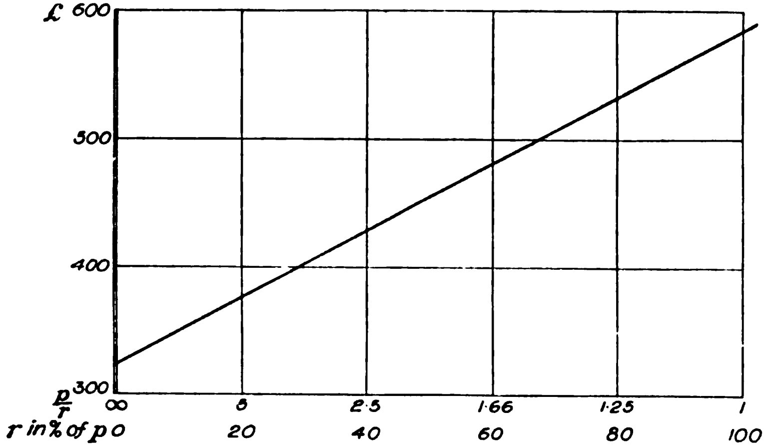


FIG. 10.

The cost of motor driving may be given by a formula of the same form as that for steam driving—

$$A' n + B' p' + C' r',$$

where—

A' is cost of wages in attending to motors, shafting, and belts per motor.
n is number of motors.
B' is interest, depreciation, repairs.
p' is total B.H.P. of motors installed.
C' is annual cost of one B.H.P. in £.

C' is given by—

$$\frac{1}{e} \times \frac{746}{1000} \times \frac{x}{240} \times \text{hours of running} \times r',$$

where e represents the efficiency of the cables and motors as a fraction of unity;
x the cost of current in pence per unit;
r' the total mean load taken over the year.

The constants in the above expression are given for a few cases by the following curves :—

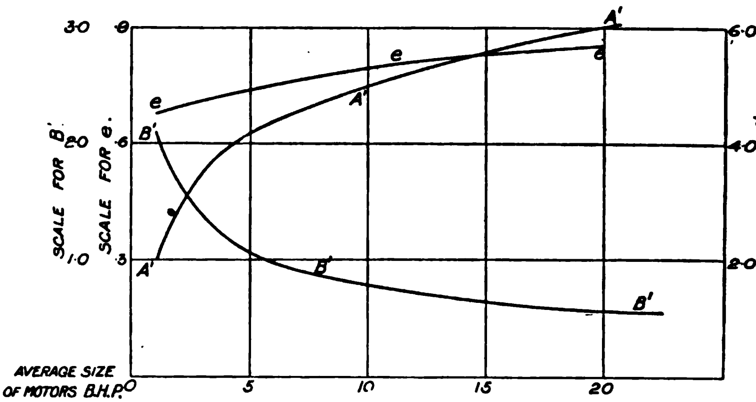


FIG. 11.—Annual Cost of Motor Distribution. Value of Constants.

Taking now a case for comparison and letting the data be as follows:—

$$p = 125. \quad r = 50$$
$$n = 25 \quad p' = 100 \quad x = 1\text{d.}$$
$$\text{giving } C' \ 11{\cdot}28,$$

we get r' 18·3 by equating the steam and electric costs, which shows us that under the assumed conditions if the mean useful load, together with the average load of such shafting as may be used for grouping, is less than 18·3 H.P., the electric is cheaper than the steam drive.

The formulæ given above are not intended to be anything more than suggestions on which each engineer may build similar formulæ by the substitution of constants suitable to the conditions which prevail in the district and in the class of work with which he may be connected.

It would be outside the scope of the present paper, which is intended to deal rather with the use of electricity, to enter into the question of its economical generation ; but the author would like, before closing, to express the opinion that, unless the saving to be gained by generation on the premises is considerable, it is wiser to procure current from an outside source and so take advantage of the reserve plant of a central station, and at the same time be entirely free to devote one's attention to one's own particular business rather than for the sake of a small apparent saving enter into the business of electrical supply with its responsibilities and troubles.

If, however, current is generated on the premises, it must not be forgotten that the use of batteries may, owing to the large fluctuations of load, be productive of considerable economy.

In conclusion, the author would point out that the subject on which he has been speaking is a very wide one, and one bristling with difficulties owing to the limited amount of experimental work which is available, and that therefore he can only hope that the paper will be useful rather as a collection of suggestions than as anything more ambitious, and that it may in some small degree help to the intelligent appreciation of the problems involved in the application of motors to machine shop driving.

The PRESIDENT: The Council thought that it might be desirable to have the two papers read at the same meeting, so that the discussion might be had on the two papers together. Of course at this late hour it would be quite unreasonable to start a discussion on these valuable papers, and therefore, I presume, we will adjourn the discussion to the the next meeting.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Members.

Frederick Giffard Cole. | Dr. George Finzi.

Associate Members.

Chas. Frederick Butler. | Robert Walter Grubb.
Harold Edward Donnithorne. | John Hayward Home.
H. P. Prior.

Associates.

John Norman Alty. | Edmund Davidson.
Gwylim Anwyl Hughes.

Students.

Walter Charles Lambourn. | Wm. Stanley Lonsdale.
Donald Grant Tyrie.

The Three Hundred and Ninety-fifth Ordinary General Meeting of the Institution was held at the Society of Arts, Adelphi, on Thursday evening, May 14th, 1903—Mr. R. K. GRAY, President, in the chair.

The minutes of the Ordinary General Meeting of May 7th, 1903, were, by permission of the meeting, taken as read, and signed by the President.

The names of new candidates for election into the Institution were taken as read, and it was ordered that they should be suspended in the Library.

The following list of transfers was published as having been approved by the Council:—

From the class of Associate Members to that of Members—

Gerald Henry John Hooghwinkel.

From the class of Foreign Members to that of Members—

Guido Semenza.

From the class of Students to that of Associates—

James Hally Brown. | John Blundell Butler.
Frank Knight Jewson.

Messrs. I. W. Chubb and J. Fiddes-Brown were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from the Astronomer Royal, Messrs. A. H. Jackson, H. M. Leaf, and the Maschinenfabrik Oerlikon; and to the *Building Fund* from Messrs. S. V. Clirehugh, W. J. Cooper, and W. McGeoch, to all of whom the thanks of the meeting were duly accorded.

The PRESIDENT: Before beginning the discussion, I have to announce that the Council this afternoon, believing that it would meet with the general approval of the members of the Institution, have decided that the Annual General Meeting should take place at the new offices. We thought this arrangement would give an opportunity to the members to see the new offices, which will be found spacious and commodious: it was also thought that the convenience of members would be better met if the hour were changed from 8 p.m., which is the usual time of our General Meetings, to 5 o'clock in the afternoon. You are aware that we are debarred from having any technical paper read at those meetings, and it appeared to be superfluous and to cause unnecessary inconvenience to bring people together in the evening at 8 o'clock to hear read the Annual Report of your Council, which

contains matter of which to a great extent the members are already aware.

I have no doubt, gentlemen, you will confirm the Council's decision.

RESUMPTION OF DISCUSSION ON PAPERS BY MR. A. D. WILLIAMSON, ON "APPLICATIONS OF ELECTRICITY IN ENGINEERING AND SHIPBUILDING WORKS," AND MR. A. B. CHATWOOD, B.SC., ON "ELECTRIC DRIVING IN MACHINE SHOPS."

Mr. H. A. MAVOR: I am glad to have an opportunity of expressing my thanks to Mr. Williamson for this paper. It is one of the most useful and practical papers that we have had before us, and one that lends itself to useful discussion. There are some points in it which, with your permission, I would like to emphasise. We have on page 930 an interesting table of Works Costs. I have taken the opportunity to compare these costs, not with those of other electric installations, but with an entirely different group of costs. Mr. Mavor.

It has always seemed to me important in considering the costs of electrical production, more especially in factories, that we ought to place ourselves, not only on all fours with what we and our friends in the same business have been able to do, but with what is being done in other regions. I happen to have a pretty complete tabulated record (Table I.) of a group of costs taken from different parts of the country and over widely different industries; and I have found it interesting to compare these costs with one another. For the sake of convenience I have reduced them to terms of cost per unit, by translating the indicated horse-power into units by taking 600 watts per I.H.P.; and also for convenience I have translated the coal into a uniform price of 10od. per ton, which is a convenient figure for calculating, and not very far from about the average cost over the country. That works out to 0·045d. per lb. Having the figures in that form, it is easy to see how many pounds of coal are being used per killowatt or per horse-power as the case may be. I find that the best kind of business for economical power production is to be found in weaving and spinning factories. Flour mills are nearly as good; and the very worst and the most expensive power production in the whole range of British industry that I have been able to find is in engineering workshops. That is not difficult to explain, and it is interesting in this connection, because we are here dealing with an engineering workshop. It is pleasing to find that in this workshop the costs of power production are not hopelessly bad; but they are a good deal worse than the best, and that is the point that I wish to call attention to. I have eliminated from the comparison the repairs and the cost of water, because they may vary under widely differing conditions; and as the depreciation figures in this paper are not given in detail, I think that it would be well also to eliminate them. I have made a very simple comparison between the best record I have of power cost—it was a spinning mill in Lancashire—and the two first cases which are given in some detail on pp. 930 and 931 of Mr. Williamson's paper. The most startling difference is in the wages per unit. This is

Mr. Mavor.

TABLE I.

1897. RESULT OF INQUIRY INTO COST OF POWER COAL. PRICE CORRECTED TO 100 PENCE PER TON, ·045 PENCE PER LB.

Class of Factory.	Hours per Annum.	I.H.P. Hours in Thousands.	Coal Weight in Thousands of Pounds.	Coal per I.H.P. Hour in Lbs.	Coal per I.H.P. Hour in Pence.	Wages per I.H.P. Hour in Pence.	Oil and Stores per I.H.P. Hour in Pence.	Total Cost per I.H.P. Hour in Pence.	Per Unit.
Weaving	2,888	2,550	6,450	2·5	·112	·013	·011	·136	·227
Spinning	2,800	2,350	5,250	2·25	·1	·02	·012	·132	·220
„	2,850	640	1,740	2·72	·122	·04	·013	·175	·292
Flour	5,500	1,920	5,000	2·68	·12	·036	·013	·169	·282
Engineering	2,700	360	1,720	4.8	·214	·068	·013	·295	·492
Corn Mill	6,000	2,160	4,350	2·0	·09	·043	·012	·145	·242
Thread...	2,800	15,300	55,000	3·5	·156	·025	·01	·191	·320
Tweed	2,900	1,000	6,000	6	·27	·073	·014	·357	·595
Paper	7,312	5,120	25,500	5	·222	·025	·01	·257	·43
„	7,200	2,400	11,200	5·65	·207	·04	·015	·262	·437
Chemical	6,500	2,400	12,200	5	·222	·02	·002	·244	·407
Paper	6,700	4,690	18,000	3·85	·172	·032	·01	·214	·357
Engineering	2,808	200	5,570	27·85	1·25	·18	·03	1·46	2·433
„	3,100	540	10,000	18·5	·825	·09	·03	·945	1·575
Sugar Refining ...	6,900	320	4,500	14	·625	·16	·012	·797	1·33
Paper	7,000	6,300	31,000	4·9	·22	·052	·011	·283	·472
Shipbuilding	2,650	530	8,200	15·4	·69	·154	·08	·924	1·54
Electrical Engineering	—	—	—	—	—	—	—	·503	·838
Chemical	—	—	—	—	—	—	—	·18	·3

a point which I think deserves our most careful consideration. We are quite accustomed to trust our lives in trains running at sixty miles an hour, with a man of the working class and a stoker looking after the engine, which may be of a thousand horse-power. I think you will find it not a very difficult calculation to ascertain how much that runs out per horse-power per hour. It is not much; it is not anything like a tenth of a penny per unit. The best record that I have been able to get of actual results from year's end to year's end in wages is the equivalent of 0·022d. per unit in a spinning mill which also has a very low consumption of coal. To-day I took the opportunity of going through the valuable tables in *Lightning* for power productions. I am very much surprised to find that one of the cheapest power-stations is in London—Westminster, which is 0·16d. per unit, Bradford and Edinburgh being each 0·09 per unit. Each of these latter is four times as high as it is in the spinning mill. Those of us who are familiar with the conditions of working in such factories, where power is a very important element in the prime cost, and where consequently it has been carefully sought to reduce it to its lowest figure, know that the conditions there are very different from what they are in an electric generating-station. I think it is time that we electrical engineers should realise that it is not necessary to have expensive labour for looking after electric machinery. If we do not believe it, then users of electric machinery are not likely to be convinced that they can dispense with expensive labour. I am glad to find that Mr. Williamson has grasped this point. I do not offer this by way of criticism, but for the purpose of emphasising what, among the multiplicity of other matters, he has not been able to so fully call attention to. I think that it is this very point of labour cost which leads Mr. Williamson to recommend large units running at slow speed. Mr. Mavor.

Larger units would necessarily result in a very great difference in coal economy. In fact there is considerable room for coal economy in the cases under consideration as compared with the spinning mill I have been referring to. The cost, correcting the price of coal to 100d. per ton, is 0·168 per unit at the mill, as against 0·27 in works (*a*), and 0·29 in works (*b*). I may incidentally point out here that I do not quite understand Mr. Williamson's comparisons. He says there is a difference of the tenth of a penny. I think that is largely due to coal being cheaper in the second works. The actual saving appears to be about the half of that, when the coal is reduced to a common figure for cost.

The use of low-speed units is another important point which I should like strongly to advocate here. Those of us who are building dynamos know that the attention which a dynamo requires is entirely at the commutator, and that if you have a high-speed commutator, there is necessity for frequent adjustment and attention from the attendant; and that as our units increase in size, we ought, if we use high-speed engines, to keep the commutators as small in diameter as is consistent with proper working, and have the surface speed as low as possible.

Then Mr. Williamson recommends an increase of voltage. It is easy when one looks over an installation of this kind, with over

Mr. Mavor. 10,000 horse-power, to say what a pity it was not begun on better lines; but we must not forget that experience has to be gained, and experience here thoroughly confirms what one would expect, namely, that higher voltage and the three-wire system would be recommended for future extensions, as Mr. Williamson mentions. I think one of the most important features in the improvement produced by the use of bigger units, is the abolition of the switchboard with all its complications. The abolition of compound winding is a natural consequence of the increase of size, because the percentage drop on big units is much less than the drop on small ones. With big units there is no necessity for any switchboard at all. Switches for heavy currents are very ornamental and expensive; but every one knows that the last thing one thinks of is to switch off the heavy currents at the switchboard. Those switches are never used, and therefore ought not to be there. The abolition of the switchboard abolishes the switchboard attendant and his cost. One point I would like to ask Mr. Williamson is, Can he give us any record of the breakdowns that have taken place, and the nature of them? He mentions that the engines when opened out show very little wear on the cylinders; but what about the valves, and what number of breakdowns have been recorded in the course of working? I expect that his answer will be that they have been extremely small. I wish to use this as an argument for reducing the number of units; we only have one engine on an express train; we have very many steamers crossing the ocean with only one engine—at most two; and therefore it does not seem as if there was any sense in having five or six units in a power-station. On page 935 of his paper, Mr. Williamson very rightly points out that the varying methods of applying motors to machines do not in themselves result in great differences in economy. The real point is that, after all, electricity is only a means of distributing power, and that economy is to be got in the generating station. The loss in shafting is frequently very high, but I do not think we always remember that the interest on the cost of the electric plant is also high. The real argument for adopting electric drive is the possibility of introducing economical plant into the generating stations. Then with regard to the speed, weight, and price of motors. If I may be pardoned for introducing a personal suggestion of my own here, I think that if we want slow-speed motors, we cannot do better than turn them outside in—put the armature outside the magnet, and you at once get a very high speed for the wires on the rotor of the machine—a high peripheral speed without a high rotative speed. The difficulties of lubrication have been solved and there is not any difficulty left. Some of the older members of the Institution will remember that there was a machine in the very early days in which there was a fixed internal magnet—the Elphinstone-Vincent machine; that is capable of development in a very satisfactory way. I had the pleasure of showing last year at the Institution of Civil Engineers a motor constructed on this principle, which gives exceedingly low speed with a very small size—a one horse-power motor, at 500 revolutions, only a foot in diameter and a foot long.

Mr. Selby Bigge. Mr. D. L. SELBY BIGGE: I have read this paper of Mr. Williamson's

with the very greatest interest. For the past fourteen years I have been engaged in the work upon which Mr. Williamson touches—that is, the application of electric power to the driving of works and different industries. I think that this paper is of the very greatest value. It is practical and sound from beginning to end. The points that Mr. Williamson brings forward, as he says, are facts within his own experience, and they should carry great weight, I think, with the members of this Institution. All the points that he brings forward most thoroughly corroborate all the statements that other writers on this subject have put forward; in fact, my views so thoroughly coincide with those of Mr. Williamson upon those points, that it is very difficult for me to criticise what he has said. In going briefly through this paper I find, looking at page 926 in the first instance, that Mr. Williamson has had to deal with works which have been gradually growing, and it has been very difficult for him from the outset to formulate a scheme for the whole of those works. I have always found that it is of the very greatest importance when considering a scheme for a works to take the whole of the works into consideration from the outset, and as far as possible to take all possible extensions into consideration; and when you have arrived at the whole of the power that the works are at the present time using, and what they are likely to use in the future, then total that power up. Supposing that the power amounts to 2,000 or 1,500 horse-power, for the sake of argument, you then immediately split up that power into certain fixed units; and I think that the greatest economy can be derived from the plant in which there are never more than two units working at the same time. That to a certain extent bears out what Mr. Mavor has just now said on the subject of large units and in favour of having few units working; but I can fully appreciate the great difficulty in Mr. Williamson's case that he had in that direction. I had the pleasure of visiting Messrs. Vickers-Maxims' works, when Mr. Vickers showed me all round the works at Sheffield, so that I have some slight knowledge of the conditions that Mr. Williamson had to tackle. I must say that the result has been most satisfactory. In the case of the engine-works power-house I see that he has allowed for five sets; it seems to me that to get the greatest economy out of such a generating plant there are too many units, and that it would have been better if it could have been so arranged as to have made units larger and never to have more than two running at one time. There are cases in which we have very large works being driven off one unit, and then you have only the one superintendence of the one unit to provide for. Of course you have the standby plant as well. On page 932 Mr. Williamson states that his experience of "high-speed vertical engines running under the severe conditions of continuous heavy loads has been perfectly satisfactory." I can thoroughly corroborate that, for up to certain horse-powers I have found exactly the same thing. But in the case of getting up into very large horse-powers, such as 1,000 horse-power, 1,500 horse-power and upwards, we then have found the greatest economy resulting from either triple expansion engines and generators running at slow speed, or the compound horizontal flywheel type engines and generators, with condensing arrange- Mr. Selby Bigge.

Mr. Selby Bigge.

ments and superheated steam up to a moderate number of degrees, to dry the steam thoroughly, with all accessories such as Green's economisers, water-cooling towers, and appliances of that kind. I next come to the question of cables, which is referred to on page 932, and I notice that a light insulation is used to avoid short circuits. That may be very useful. Of course you have to take every case on its own merits, but after a certain number of years the light insulation generally wears off, and then you have no insulation at all. I prefer as a rule to keep the conductors as far as possible bare. Coming to the motors, Mr. Williamson says, "It must be owned that most of the success of electric driving has been due to the great improvements which have recently been made in manufacturing motors." That undoubtedly is a very great point. The construction of motors in recent years has advanced enormously, and breakdowns are almost unknown now with well-constructed, carefully made, motors. "At the outset a strong effort was made to cut down the number of sizes of motors." That is another point which I think is very important also in works, that you should have as few numbers of sizes of motors as possible, so that one set of spares will do for the whole of them. On the question of gear, Mr. Williamson says, "Friction gear is inefficient and cannot be applied for large powers." I quite agree with that. Also he says, "Belting is of course applicable to nearly all cases, the slipping being a positive advantage where heavy shocks and reversals of machines take place." I can thoroughly corroborate that. On the question of variable-speed motors Mr. Williamson gives some very interesting particulars, and the case he tells us of a 5 horse-power motor with a range of from 300 to 900 revolutions for the return stroke, running at the high speed of the motor, is very interesting in the case of a lathe or planer. I notice that Mr. Williamson states that there are about 110 variable-speed motors in use at the Sheffield works, showing that they have found those to be a distinct advantage. The rest of the paper deals very largely with motor tests, and will be no doubt very valuable indeed as a reference. On page 954 Mr. Williamson gives us the specific case of the Wellman charger, which shows the very great economy that can be derived from the application of electric driving. He says, "Summing up the advantages, we have a reduction in the wage costs of melting of 50 per cent., with an increase in the output of 25 per cent." That is very strong evidence in favour of such machinery. On page 962 Mr. Williamson says, "It would be interesting to hear some experiences of engineers with circuit-breakers fitted in such power installations as those described in this paper." If I may be allowed to give my own personal experience in the matter, it is this, that we find that for small machines and small tools, such as punches, shears, and such like machinery, the circuit-breaker is in most cases a nuisance rather than a benefit, and we find it best in such a case to apply distributing switchboards fitted up with fuses to the different motors. We find that to be the most practical and sound practice. The next point which Mr. Williamson deals with (on the same page) is the saving due to electric driving. It is very difficult indeed to arrive at the saving due to electric driving unless you have absolutely parallel cases—that is,

Mr. Selby Bigge.

unless you take a works that was formerly driven by steam and completely equip it with electric power, and then compare the results after the transformation with the actual work done before. That is the only way to get at an accurate result. Some time ago I spent a very great deal of time and attention on that very point, and I tried to get a number of statistics. I found that in the majority of instances the saving due to the introduction of electric driving in place of steam (that is to say, in works such as shipyards, or works where the power was subdivided up into a very large number of units) varied between 35 and 50 per cent. That was drawn not from one case, but from a great number of different works. I got the opinions of the different works' owners and managers on that very point, asking them what they had found was the actual saving after the substitution of electric driving for steam. It varied, as I say, between 35 and 50 per cent. I see that Mr. Williamson has done even better than that, because he states that at their works the actual result was the saving of half the coal bill, with an increase of over 50 per cent. in the output.

Dr. Wiesengrund.

Dr. B. WIESENGRUND: It would be interesting to learn from Mr. Williamson whether, at least for the plants erected in 1897 and later, alternating current has not been considered; or what have been the reasons for adopting 220-volt continuous-current plants even for the latest installations. Considering the large extent of the works, it would seem likely that alternating current would have offered advantages in first cost as well as in maintenance. Perhaps the question of speed regulation gave the decision in favour of continuous current. It may be of some interest that the difficulty of speed regulation with alternating-current motors is overcome in an arrangement patented by Mr. Wüst, Zurich, who uses different stators and rotors with different numbers of poles combined in a common casing. The outputs of the different elements need not be necessarily equal; it is possible to arrange, for instance, the maximum output at the lowest speed. These motors, together with suitable gearing arrangements, give exceedingly simple designs of electric machine tools which I might differentiate from those originally designed for other kinds of drives. For the complete success of electric power transmission in engineering works it seems necessary that machine tool manufacturers and electrical engineers should work in unison, and probably this union would bring to the front designs similar in simplicity to those of which I would have pleasure in putting before you some drawings and photo prints. In these designs the motor is a component part of the machines, and its attachment to the working portion, avoiding intermediate gearing, produces a considerable saving in power and first cost of the machines, besides the latter being much more compact than the ordinary designs. The application of a continuous-current motor with speed regulation described by Mr. Williamson in a vertical planer or slotting machine, the motor reversing at each stroke of the machine, is certainly very interesting, but it can only be regarded as an example of the hard work that modern motors can stand. Whether such an arrangement is advisable from a technical point of view seems doubtful. The special conditions in planing machines, namely, slow working and quick

Dr. Wiesengrund. return stroke, make it desirable not to reverse the direction of rotation of the motor, but to make use of the kinetic energy accumulated during the working stroke in the motor or a flywheel for the quick return stroke, and only to raise the speed of the motor together with the reversal of the machine. An arrangement similar to that adopted in a hoisting drum, namely, two bevel wheels always engaging with the driving wheel on the motor shaft, the wheels being operated by a friction clutch, the coupling to the machine formed as a flywheel would answer the purposes. With a multi-speed Wüst motor it is very simple to change direction of motion of the gear and motor element in circuit by means of one lever automatically. In such a case a short-circuited rotor can be used, as the motor can be started in the central position of the clutch without load. It would be interesting to learn whether any experiments have been made in this country to regulate the speed of continuous-current motors by means of altering the depth of the air-gap. Mr. Wüst has designed, patented, and successfully applied this principle to many motors with two, four, and more poles, always operating with a single lever. With regard to the gearing, it would be interesting to hear whether any experiments have been made at Messrs. Vickers, Son & Maxim's with double helical wheels. The advantage of such wheels is the entire absence of back-lash, ensuring noiseless running, especially if the wheels are machine-cut out of the solid, as patented and manufactured by Messrs. Wüst and Co., Seebach-Zürich. As double reduction gears, in a special arrangement made as a substitute for worm gears, for reductions up to 1:60 a minimum efficiency of 90 per cent. can be guaranteed.

Mr. Allen. Mr. W. H. ALLEN: In reference to the driving arrangements shown on page 935 of Mr. Williamson's paper, nothing is said with reference to the resistance which is given in the matter of shafting. When we designed the works at Bedford I thought that we might bring about economies in some directions by improvements in the mechanical movement, so I sent round to a large number of works in this country and in America to compare notes how they distributed the resistance from the generating power independent of the drive, that is whether it was mechanical or electric. We found that the average was something as follows: one-half of the power was expended in the shafting, the other half was expended in the movement of the tool and the work done. No tool maker has yet made any determination to try and improve the efficiency of the tools, and it is lamentable to see what a large amount of effort is taken in actually working the tool, while so very little is taken in the actual work done of cutting the metal. The best and largest tools only give us a duty of about 30 per cent. of the total generating power, while in the case of the smaller tools they give us as low as 10 or 15 per cent. Nothing much can be done, however, in the economy of these two divisions of the generating power; but in the matter of the shafting we have been enabled to show a very considerable saving by dispensing entirely with the top gearing. The power taken for driving the shaft may be divided as follows: it is 50 per cent. for the whole shaft, 25 per cent. being for the shafting pure and simple, while the top gearing absorbs the other 25 per cent. If the

latter can be dispensed with, we have a wholesale saving of 25 per cent. of the total generating power. At Bedford we made an effort to save that, with very considerable success, by eliminating top gearing and substituting a cone or sleeve on the shafting itself, which was worked by a cone clutch. It may surprise those who have never gone into it, to learn that of the whole number of tools at work in an engineer's shop, nearly half are idle all the day long; only 50 per cent. of the tools are actually at work at the various processes which they have to perform. When tools are idle, under the old mechanical form of drive, you have to work the top gearing and the belting at a loss of 25 per cent., whereas at Bedford, by the means we have employed there of using the cone, the moment the machine is out of gear the whole of its resistance is saved against the generator. I hold that to be a very considerable saving. It has been adopted by several other gentlemen who have built works since we started. There is one other advantage in the employment of this particular form—that is, that each tool can be driven separately by an individual motor in case of emergency, as for overtime or in the dinner-time. We have a small barrow in which there is a motor which is wheeled up to any particular tool, and in a few minutes that tool is at work independently of the main generating plant. As I have said, the saving derived from the method we have employed at Bedford is as much as 25 per cent. of the whole of the generating power from the main engine. I think that is worth knowing in designing works of this description. Mr. Allen.

Mr. J. S. FAIRFAX: Mr. Williamson, in his most excellent paper, says that 1,311 motors have been applied to driving eleven different classes of works in seven different districts or workshops throughout the country. It seems to me that the experience which he gives us will be of the utmost importance and advantage to both mechanical and electrical engineers. He states also his experience of the gearing that he has employed. He has used seven different kinds of drive, but the only three which he feels are to be depended upon are spur gearing, belting, and chain gearing. So far, the machine tool makers have designed their machines from the line shafting, and therefore when you apply electric motors to the driving of these tools there is a great difference in the speed, which must, of course, be reduced by outside gearing. Mr. Williamson seems to have endeavoured to standardise his speeds as well as the dimensions of his motors, for it appears that the majority of them (although, of course, there is a great deal of discrepancy according to the work) were run at about 600 revolutions per minute. The electric motor builders do not seem to have met that problem as much as they might have done. They might have used some mechanical means for reducing their speed to a speed somewhat approaching that of a line shaft, as the full motor speed is seldom required. Mr. Williamson has used his variable-speed motor, and found it a very great success. Certainly it is an advantage to use it for many reciprocating tools, and also for drills and boring machines, and tools of that sort. I think his motor is capable of very large development in the future. Incidentally it is readily used to measure the power given to each tool under different conditions of working, Mr. Fairfax

Mr. Fairfax. and may thus bring about a great saving of power, as suggested by Mr. Allen. I have been giving some little attention to this matter of motor driving, and I would apply the gearing directly on the motor—whether it is an engine or an electric motor makes no difference; and instead of doing it in the usual way by reducing the speed outside the motor, I would make the motor pulley—supposing it is driving a belt—go round a fewer number of revolutions than the armature shaft. The model that is here is part of the motor itself, and gives a reduction of about 17 or 18 per cent., but the principle is capable of going up to about 35 or 40 per cent. reduction, so that in a case where you are using motors that have an armature speed of 600 revolutions a minute, the arrangement shown by the model would give, say, 400 revolutions a minute at the pulley. Then, if you were to put in a second pulley, as there is in the model, you could get a variation of speed. By turning the little steel shaft round there, you will see that the model shows three different speeds. There is a variation of about 1½ per cent. between those two pulleys, but you can make the variation much greater than that. If you put on an outside bearing, you can have four pulleys, and suppose the armature shaft is running at 1,000 revolutions, you can reduce down one pulley to 800, the next to 750, the next to 700, and the fourth to 650. You will notice the peculiarity that, although all the pulleys are of the same diameter, they give four different speeds, so that you can drive on to a drum on a lathe, dispensing with cone pulleys, and change your speed while the machine is running, so that you have not to stop the machine at all. You can do that from each end of the armature shaft. If you want the greatest reduction possible, without variation, you simply put on one pulley and make your full reduction on that. There is another arrangement by which speed can be reduced from perhaps 5 or 10 to one. The great point is that it can be put on any motor and be self-contained without any outside bearing whatever, so that the motor can be hung up on a ceiling, or fastened immediately to the wall, ready to drive a machine.

Mr. Barker. Mr. J. H. BARKER: I would like to controvert Mr. Mavor's remarks about the locomotive. He says a locomotive on a main line is run with no standby. Although the locomotive is reputed to be so reliable as to need no duplicate, yet if it is worked out, we find that the run per engine is only about fifty miles a day; the rest of their time is spent in the repairing shop. As a manufacturer, I should be very sorry to trust to a single locomotive in my power-house.

Mr. Russell. Mr. S. A. RUSSELL: I have read this paper with very great pleasure on account of the great number of facts which it lays before us. The paper is indeed so full of facts that it lends itself very little to criticism. I think that, perhaps, the best way of taking part in the discussion will be to give a few notes of my own experience of motor-driving at the Silvertown factory of the India Rubber Company. The whole factory is not driven electrically, as we have many good economical engines driving through small amounts of shafting, and it was decided that it would not serve any useful purpose to replace those engines by electric drive. We had, however, plenty of engines a good deal older which were not very economical, being supplied through long ranges of steam

piping or transmitting their power through a great deal of shafting. We commenced by replacing those, and also by fitting electric drive to all extensions and new work. In that way we have arrived at a total of over 150 motors aggregating about 3,500 H.P., and varying in size from 150 H.P. down to 1 H.P. The class of work done is very various and is of a very intermittent character, and many of the machines at one part of the operation take several times as much power as the average. Our 3,500 H.P. of motors does not call for more than a maximum of 1,200 k.w. from the generating station, and the average output taken over all the hours of running is only about 300 k.w. That is partly due to the reasons just named, and partly also because we have to run at night for a very small load. I am sorry to say we cannot show such good results in the cost of generation as those that Mr. Williamson gives in his paper for the Sheffield Works. At the present time our plant is not working condensing, but we hope that it will be so shortly; and that, coupled with the low load-factor, makes our costs more like those obtained at Erith and Barrow than those very excellent ones which were obtained at Sheffield. As to the class of work that we do with electric drive, we use it for tools such as lathes, planers, drillers, and wood-working machinery; for machines for making rubber and guttapercha where we get very varying and heavy loads, for cable-making machinery, and for a number of general purposes, such as driving stamping presses, pumps, air presses, lifts, cranes, pile drivers, capstans, and fans. With regard to the question of separate motors for each machine or group of machines, we have made a general rule that any machine requiring more than 5 H.P. should have a separate motor, but we depart from this in various cases. For instance, we have a line of similar machines driven from a line shaft, and there we find it better not to drive all by one motor, nor to put a motor to each machine, but to divide the big group up into two or more smaller groups each with its own motor, arranged so that practically any number of machines can be used according to the requirements without ever having any appreciable amount of idle shafting or machinery running. Also we have found it advisable with machines such as stamping presses, punches, and planers, where there is a considerable variation in the load during a cycle of the operation, to group two or three together on a motor if it can be done without loss through a great deal of idle machinery running, the object being to save having to put heavy flywheels on the motors to overcome the variation of the load. We have also a number of motors smaller than 5 H.P., but we have avoided those as much as possible. It is necessary sometimes, owing to the position of a machine in the shop, or owing to the nature of the work, to use smaller motors, but I think that the extra capital cost and the lower efficiency, and, in the case of very small motors, the extra cost of maintenance, all tend to make it uneconomical to use motors of much less than 5 H.P. We therefore avoid them when possible. With regard to gearing, Mr. Williamson has named spur-gearing, chain-gearing, and belting as the only three gears which have given satisfactory results. We use all three of those, but we also use a great deal of worm-gearing, not for small loads or intermittent work,

Mr. Russell.

Mr. Russell. but for driving slow-running machinery which in some cases takes up to 150 H.P. per machine. The machines are used in the manufacture of rubber, and they have a very heavy and varying load. We have found that worm-gearing has given us very satisfactory results. It is impossible to make accurate measurements of efficiency with a load varying in that way, but in comparing machines driven through worm-gearing and machines driven through a train of spur-wheels, we cannot find any very appreciable difference in the amount of power taken by the motors. I do not think the loss is anything like so considerable as many people suppose, if the worm-gearing is well made. I might mention that we are not using ball thrusts, but a thrust block something like an ordinary marine block; but the collars on the shaft, instead of being part of the solid forging, are separate collars threaded on feathers with distance pieces in between. These have been made separately, because we can more easily harden them and get a much better surface, and that makes an enormous difference in the friction losses. The rings in the block are phosphor-bronze rings, and between the collars and the rings are two loose rings, one of phosphor-bronze and one of steel, to reduce the surface speed of the rubbing parts. We have had these thrust blocks and worm-gearing in use for over two years, and the wear on the worm and thrust is quite inappreciable. They take up much less room than a train of spur-wheels, and they run much more smoothly and silently under a varying load. The cost of the worm-gear at various places where we have compared alternative schemes seems to run about 15 per cent. higher than the cost of spur-gear. With regard to chain-gear we have not had much experience, as we have only a few drives with it, but we find it most useful where two shafts cannot be put far enough apart for a belt drive, nor close enough for spur-gearing. We find the chain-gearing is from 25 to 50 per cent. dearer than spur-gearing, and I should be glad to hear from Mr. Williamson whether he finds that there is that difference in his experience. Another matter which is referred to in the paper is the type of motor and the improvements made in recent years. All our recent motors are of course multi-polar with slotted cores, but we have a large number of smooth-core motors, both bi-polar and multi-polar, which have been in work for a number of years. There is no doubt that the small wire-wound armature with the smooth core is very inferior to the former-wound slotted-core armature. With the smooth-core machines with drum-bar armatures we have got very excellent results, and we have had motors which stand very severe work. We have several of 75 H.P. with smooth cores, which have been running for five or six years driving rubber machinery, where the load frequently varies from absolutely light load (that is, merely driving the machine round) to 25 or 50 per cent. over full load as the rubber enters and leaves the rolls. I am pleased to say that during all this time we have not had a breakdown of an armature on one of these machines. I think that shows that the smooth-core machine is really capable of doing a great deal more than many people credit it with. I should put the change from copper to carbon brushes as almost a more important change in allowing us to deal with motor drives as we do now. About

circuit breakers, we have tried circuit breakers in the circuit of our motors, but have had to give them up and to revert to fuses, as we find that they are very uncertain. In the shops, of course, they are exposed to a certain amount of dust and a certain amount of damp, and we were continually finding that the circuit breakers stuck. Mr. Russell.

Mr. E. KILBURN SCOTT: One thing which should be borne in mind in applying electric motors to a shop which has already been driven by shafting is the flywheel capacity of the motor. In making a motor we always try to get the armature and moving parts as small as possible; but if you put a motor to drive machinery which has already been actuated by line shafting, having a large number of pullies and belts and so on, you have there a good deal of flywheel power, and therefore, in applying motors to such machinery, it is well to provide flywheels on the motor shafts or else in the gearing. It might pay to reconstruct the motor, and as I suggested some time ago, build the armatures very large indeed—in fact build the armature outside the field so as to get increased diameter and weight. Mr. Kilburn Scott.

In one of the largest railway works in this country I recently noticed an overhead travelling crane which is somewhat novel. The travelling and traversing motions were driven by means of electric motors in the usual way, but in this particular case the heavy lift was effected by a pump and hydraulic mechanism on the crab. The pump was driven by electric power, and a very nice exact lift was obtained by means of the hydraulic ram, which, I believe, would not have been possible if the electric motor had been coupled-up direct.

The authors of both these papers have dealt only with continuous-current motors, but I do feel that in this motor work we are coming to driving by three-phase. From a purely manufacturing point of view, one finds that in plants fitted with three-phase motors there is never any trouble about breakdowns or difficulty with the starting gear. But with the continuous-current motors you may have a breakdown if the "no load" or "overload" release gets out of order, or, as sometimes happens, they are tied up to prevent them acting. It is the nature of the continuous-current motor to be coddled in this way, and, moreover, even if there is no sparking an attendant must go round regularly to fit new brushes. With a three-phase motor, having a short-circuited rotor, such as are used for driving a good many modern workshops, there are no brushes, and the starting switch is of the simplest kind with nothing to get out of order or be tied up. Again, more often than not motors get into dusty places, and a cover must be provided to protect the commutator, or the motor may have to be entirely enclosed and its output considerably reduced. Now I believe the enclosed motor is distinctly a fad, and it is very seldom, if ever, necessary with the much simpler three-phase motor.

Another point in connection with three-phase is that the motor speed depends primarily on the periodicity. And as most machines require a steady speed, the three-phase motor is thus very desirable. This feature is particularly useful when driving textile machinery, as is proved by the extensive adoption of the three-phase motor in textile factories abroad. It is often urged against the three-phase motor that

Mr. Kilburn Scott. you cannot get a variable speed with it, but such variation is easily attainable. For small variations resistances can be used, and for large variations the cascade system or varying the number of stator-poles may be employed. As a matter of fact the long taper cone pulleys with a short belt between gives a very easy and cheap method of varying speed for large lathes, etc. I do not think, therefore, that you can bring the objection against the three-phase motor that you cannot get variable speeds, because if need be you can get large changes by altering the stator-poles, and you can get small intermediate changes by a pair of taper cone pulleys. Another point is that if you go to the trouble of measuring up the space occupied by a three-phase motor as compared with a continuous-current motor, you will find that if you are limited to space, you will get your three-phase motor in all right where you will not get the continuous-current motor; that follows from the construction of the two machines. Whatever may be case just now, the three-phase motor is bound to come out cheaper in the end, as it is so much easier and cheaper to make.

It may be mentioned that there is very much greater uniformity in the speeds of three-phase motors: thus at 50 periods per second no synchronous speed is possible between 600 and 750 or between 750 and 1,000, and whatever the make of motor the speed will be these figures less the slip of 3 or 5 per cent. as the case may be. Without effort or trouble therefore the speeds of three-phase motors have become standardised, and this is a very real convenience when applying such motors to machines.

Mr. Gaster. Mr. L. Gaster: I can also corroborate the great advantages of applying electric driving in works. Allusion has been made to the use of the polyphase motor for driving in factories, and whilst not wishing to discuss at this juncture the merits of the polyphase *versus* direct current, I should like to mention a case which came under my notice during my visit to Roumania last year. I had the opportunity of seeing there the application on a very large scale of the polyphase motor used for boring the wells in the petroleum oil fields, for pumping the oil, and for driving all the tools in the workshop of the Company. The power is generated from a waterfall available about 25 miles away from the oil fields, and the fact that the water-power is cheaply transmitted and that the motors are sparkless when using the polyphase current, led the Company to adopt the polyphase in preference to the direct-current system. The Company is effecting great economies in using electric motors instead of the great number of scattered boilers and engines employed previously, which not only were more costly to run, but also more dangerous on account of the fire risks. The application of electric motors to the boring of wells is extending rapidly also in the Russian oil fields. I am often asked how it is that polyphase motors are not so much used here; but the reply seems to me to be simple enough, in that there has been but little opportunity here for their development up to a short time ago. There are, however, signs of an increasing demand in the near future, the reason being, that the power will have to be transmitted at a long distance from large central stations which are being established throughout the country. I

remember Professor Weber of Zürich teaching us thoroughly first as to alternating current, saying, that if you understand thoroughly the alternating current, which is the originator of the direct current, it is not so difficult to understand the latter. The progress made in the development of the polyphase motor gives every encouragement as to its future in this country. **Mr. Gaster.**

I should like to ask Mr. Williamson a question with regard to the generating plant used on the works mentioned. I notice that there is a very great difference in the cost per unit generated. At Erith, for instance, fuel costs 20s. per ton, and the works-costs there per unit are about 1·1d.; in Barrow, with a cost for fuel of 17s. per ton, the works-costs per unit are about 1·3d., while at the Electric and Ordnance Accessories Company, although the fuel costs 19s. 10d. per ton, they only pay 0·55d. for the biggest part of the works-costs per unit. Probably in the latter case it is due to the use of a gas plant (Dowson), which I notice that they have there. I see also that the present plant capacity is only 375 kilowatts, and that the annual output is only 364,000 units. Comparing the result of works (*g*) with those others where the price of fuel is the same, but where the plant capacity is larger, and the output ranging from 644,000 units to three and a half million units annually, the price at the Electrical Ordnance Accessories Company compares very favourably. I should like to know whether it would not pay in the future to have gas-generators for driving instead of steam engines? because gas engines can be made now for very large units, and they certainly have a great future before them. There is an enormous difference in the price of fuel between the two plants (*b*) and (*g*), and where fuel is dear, the economy produced in using gas engines is very great, the fuel item playing a very considerable part in the generating costs. Referring to the remark made by the author concerning the preference of fuses *versus* "overload release," I quite agree with him that the use of the fuse as a protection is a much less troublesome arrangement, but unfortunately there does not exist a sufficiently clear understanding between the different makers of fuse and fuse-boxes to produce one good type which could be adopted universally. I think that it is now time that something should be done in the matter, and that we arrive at some understanding as to the standard type to be adopted, and so do away with the existing discrepancies.

I wish to draw special attention to the following point. Some contractors say that they will make electricity very cheaply, and they put in the plant anyhow and say, "That it will be all right"; but they often omit to explain to the purchaser the proper way to treat his motor, leaving him under the impression that the motor can do wonders, but he soon finds out that in not having been provided with sufficient spare plant in case of a breakdown, the whole works have to be stopped until the repairs are done, which causes a very great loss. In factories where the value of the goods turned out by the use of the motor is of many times greater value than the cost of driving the motors, a breakdown leads to very great loss to the user of the motor. It must be pointed out that only the best class of workmanship and the best material have to be applied, if electric driving is to be used

Mr. Gaster. successfully and economically in the long run. There are several small trades like tailoring, cap-making, tobacco-cutting, etc., where electric driving could be considerably used, but the people are simply frightened away from motors on account of the troubles they sometimes give, which to my mind are mostly due to cheap and unreliable fitting up. Contractors ought not to undertake to put up motors, or any other electrical installation, at so cheap a rate as not to allow them to ensure good finish. They should remember that it will greatly assist the further development of the application of electric driving in factories, if they will explain to the would-be customer that it is absolutely necessary to have first-rate motors, sufficient spare plant, and that a judicious distribution of the driving power will make his factory more efficient. Only in this way can we safely expect a wider extension of electric driving generally.

Mr. Patchell. Mr. W. H. PATCHELL: In regard to the remarks of previous speakers in the discussion, Mr. Barker has said that locomotives only run one hour a day, and spend the other 23 in the repairing shop. I do not understand the figures! [Mr. Barker: I said they only ran 50 miles a day.] You can take it as one hour, because they often go 60 miles in the hour. I think that we might probably prove by figures that the whole of the electric plant in the country could do the present output if worked one hour a day at full load, such is the inefficiency of the conditions under which it is worked. Then Mr. Scott votes exclusively for three-phase motors. I do not think really that there is a "best" for everything. Each has its best place. I have between 9,000 and 10,000 horse-power in direct current, and I have between 9,000 and 10,000 horse-power in three-phase current; but I do not throw down my challenge and say which is the best—each has its best place. We hear a great deal glibly talked about the variable speeds of three-phase machinery; but when you ask a man who is talking like that to put his views on paper and talk about an order, he is immediately very busy—he has to go off somewhere else very urgently, and he cannot attend to it!

To come more directly to the paper, there is one important point in factory driving which I should like to know more about, if Mr. Williamson would tell us. As regards generators, they are generally wound as shunt machines. In the paper sometimes Mr. Williamson says "shunt" and in other cases he does not say whether they are shunt or "compound." Station men, in thinking of a dynamo, generally think of it as a shunt machine, because if we are fortunate enough to be supplying direct current, we want to put them in parallel with the battery, and if you start doing that with a compound machine you often get fireworks; so we generally go in for shunt machines. [Mr. Williamson: They are all shunt right through.] A small compound machine will do for small works better perhaps than a shunt; but when you get into big works, I think that a shunt machine is the best thing to put in. Has Mr. Williamson tried the compounding of motors? [Mr. Williamson: Many of them are compound.] I think that one of the prettiest things described in the whole paper is the variable-speed reversing motor. One has been in the habit of using heavy planing

machines, taking a cut in each direction, but if they are vertical machines there are difficulties in the way of doing that, and this is a very beautiful instance of the way in which the electrical engineer can come to the rescue of the manufacturer. Mr. Allen mentioned his cones, but I do not think that he said enough in favour of them. I was greatly struck by the use of them on small tools when I went through the Bedford shops some six or seven years ago. They are not only very handy, but they save in the construction of the shop, and they also save light. You get the light down far better if you have got no horizontal belts from the main shaft across to the counter shaft. Mr. Russell spoke about smooth cores and slotted cores. I have tried both. I have had smooth cores with steel teeth; in the course of time they chafed through—the machines I am speaking of now are probably ten or twelve years old, and the machines of that date got rather warmer than machines do nowadays; that helped the cutting through, because the expansion during load slackened up the insulation, and then when we ran up again we got more chafing. As time went on we got machines with wooden teeth; they did not short-circuit on the steel pegs, because there were no steel pegs to short-circuit on; but if you happened to have a short-circuit outside, you could take the teeth out by the handful! Mr. Patchell.

Mr. R. HAMMOND: It is a very great pleasure to have results placed before us in so exact a manner as they are in Mr. Williamson's paper. It is a tempting paper, but I will just confine myself to discussing the point of cost of production. Some years ago, on one of the earliest Power Bills, Mr. Williamson was produced as one who could show that electricity could be generated and distributed at under one penny per unit, which in the dark ages of 1893 was considered a very low price indeed. Here he shows that in the two Sheffield works he has brought the costs down, in the one case, to 0·716d., and, in the other case, to 0·675d. He certainly does demonstrate a fact that is often questioned, namely, that it is quite possible to produce and distribute electricity at a profit at a penny per unit. With the average costs that appear in the Journal that was referred to by Mr. Mavor of 1·5 and even 2d. per unit, Parliamentary Committees wonder how it is that any portion of the power can be produced at so low a figure as 1d. per unit; but here we have it in black and white, and that most satisfactorily disposes of the idea that it is an impossibility. I should like Mr. Williamson in his reply to tell us how it is that his coal comes out at so high a figure. With such a magnificent load-factor I should have thought that the coal would be less, in the case of the North Sheffield station, than 0·315d. per unit, and in the case of the South Sheffield station, than 0·255d. per unit. We are well acquainted with stations in this country which, working on the very moderate load-factors of 10, 11, and 12 per cent., are achieving results equal to that; and I am curious to know, as I am sure we all must be, how it is that, at Sheffield, so high a proportion is absorbed for coal. Possibly Mr. Williamson in his reply will be able to give us an idea of the calorific value of the Sheffield coal. The very high cost of coal seems to me to be the only weak spot in the paper. Mr. Hammond.

Mr. Patchell.

Mr. W. H. PATCHELL: Mr. Hammond got very near it, but he did not quite hit the bull's-eye this time. The figure for coal in the paper is per unit generated, and the coal that Mr. Hammond has in his mind (which he has got from the *Electrical Times* tables) is coal per unit sold —which is a very different thing.

Mr. Hammond.

Mr. HAMMOND: Thank you; I am very much obliged to you for pointing that out.

Dr. Rhodes.

Dr. W. G. RHODES (*communicated*): One of the points naturally arising out of Mr. Chatwood's interesting paper is the choice between alternating- and direct-current motors for machine driving.

As the author points out, where the speed of the machinery is required to be constantly varied between wide limits the advantage lies with the direct-current motor, but if, as is often the case, the speed should be kept as constant as possible, the alternating-current motor has decided advantages. In private installations the current taken by the motor at start is not a matter of great importance, and an induction motor of the squirrel-cage type can now be made to rival the shunt-wound direct-current motor both as regards efficiency and constancy of speed, and at the same time is quite free from sparking troubles, which constitute the great drawback of direct-current machines. Not only is the fire risk less with induction motors, but they require less attention and cost but little in repairs.

I must say that I differ from the author in advocating the purchase of power from Corporations. It is quite true that the large margin of power available is an argument in favour of this; but where the demand is large it is far cheaper to install a generating plant, on account of the lower standing charges and the fact that there is then no network of mains which have to be paid for out of revenue. It not unfrequently happens, too, that a Corporation refuses to connect motors above a given rated power, on account of their inability at certain times of coping with such a large additional demand.

The lowest charge made, to my knowledge, by any Corporation for energy is 1d. per B.O.T. unit, and this charge is only reached after a certain minimum demand is guaranteed. If, as is frequently the case, there is available steam, a private installation can generate at a cost of ½d. per unit; in fact it can be done at this price including all charges for interest, depreciation, etc., by installing a gas engine with direct-driven generator.

The precaution of arranging that the voltage of the private installation should be the same as that of the town supply is a very wise one, for then the latter can be counted on in an emergency.

Mr. Aitken.

Mr. JAMES AITKEN (*communicated*): With regard to Mr. Williamson's choice of a voltage under 250, I agree with him that it will meet the requirements of all ordinary-sized works. If this pressure is exceeded, certain restrictions are imposed by the Board of Trade, and special care has to be taken in the selection of suitable controllers for voltages of 400 and upwards to prevent sparking. In the works I am connected with—the class of machines are ship-yard tools—we have adopted the individual motor drive for the machines, and, wherever possible, have used direct spur-gear drive from the motor to the

Mr. Aitken.

machine, the gear consisting of forged steel pinions and steel-rimmed wheels machine-cut. In using spur-gear care should be used in selecting the motor, as the ordinary motor for belt drive is generally too light in the armature spindle, and causes chattering. Until recently it was difficult to get motors suitable for spur-gear; these can now be obtained, and there is no reason why spur-gear should not be more generally used, and thus do away with the belting and attendant pulleys.

On page 1004 is a list of a number of machines showing the current taken, horse-power to drive the machine, and horse-power doing useful work. It may be interesting to compare these with the list in Mr. Williamson's paper. The tests have been taken from the machines working under normal conditions.

It will be noticed that in many cases the power consumed in driving the machine empty is a very great proportion of the total power used. This is also shown in Mr. Williamson's results. The object one should keep in view is therefore to get your motor as close up to the work as possible.

As an example of this, take a high-speed radial drill running at 400 revolutions per minute with $\frac{3}{4}''$ twist drill.

Horse-power registered to drive machine	7·5
Horse-power registered to drive machine running light ...	5·0
Horse-power doing useful work	2·5

This machine is direct spur-geared in the usual way. If a variable-speed motor be placed on the drill-spindle saddle, and direct connected to the drill spindle with a pair of bevel wheels, 4 H.P. would be saved. In the latest practice this method is being adopted.

With regard to the fluctuation of the load, the cranes give the most trouble, as they take a large amount of current for short periods. If the

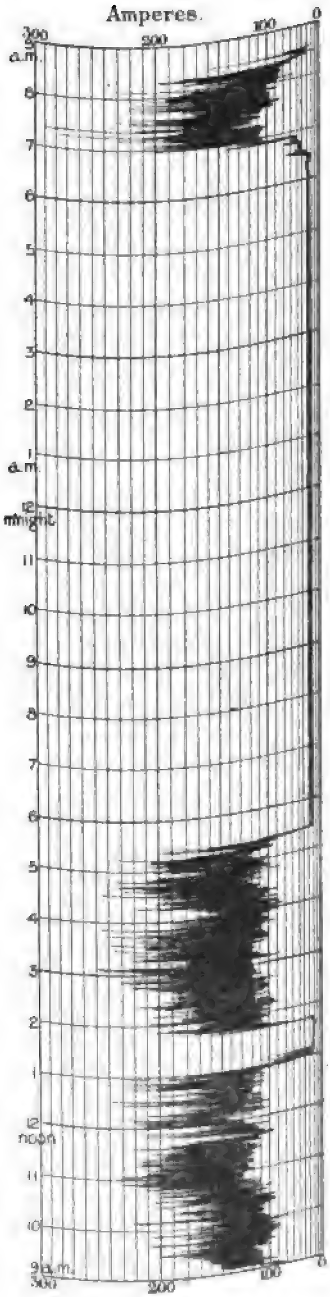


FIG. A.

List of Machines, with Horse-Power Required, etc.
220 Volts. (Aitken.)

Type of Machine and Work operated upon.	Amperes required by Machine.	H.P. to drive Machine.	H.P. used for useful Work.	Remarks.
Cold Iron Circular Saw, cutting 14" × 6" R.S.J	12½	3·68	2·2	Drive, direct spur-connected, steel wheels.
Ditto, running light...	5	1·48	...	
Iron Band Sawing Machine, cutting solid steel Bloom 3" thick ...	7	2·06	·58	Drive, direct spur-connected, steel wheels.
Ditto, running light...	5	1·48	...	
Joist Straightening Press, straightening 5" × 4" × ⅝" steel angle ...	15	4·42	1·36	Drive, direct spur-connected, steel wheels.
Ditto, straightening 16" × 6" R.S.J.	70	20·6	18·54	
Ditto, running light...	7	2·06	...	
Large Double-punching Machine, punching 1" holes through ¾" plate	20	5·9	·6	Belt drive, very heavy flywheel.
Ditto, running light...	18	5·30	...	
Punching and Shearing Machine, shearing ⅝" plate, punching ¾" in ⅝" plate...	35 average	10·3	7·38	Drive, direct spur-connected, steel wheels.
Ditto, running light...	10	2·93	...	
Combined Punch Shears and Angle Cutter, cropping 6" × 4" × ⅝" steel angles...	45	13·3	9·9	Drive, direct spur-connected, steel wheels.
Ditto, running light...	12	3·40	...	
Battery of 4 Radial Drills, broaching out ⅝" holes to ¾"...	15	4·42	2·94	Drive, direct spur-geared to underground shaft. Machines bevel geared to shaft.
Ditto, running light...	5	1·48	...	
Stancheon Facing Lathe, facing stancheon one tool ⅜" cut × 1/16" feed	10	2.93	·87	Drive, direct spur-geared to headstock.
Ditto, running light...	7	2·06	...	
Horizontal Drilling Machine, drilling ¾" hole, 160 revs., twist drill ...	10	2·93	1·45	Belt drive.
Ditto, running light...	5	1·48	...	
Joist Milling Machine, milling 10" × 5" R.S.J.	12½	3·68	2·2	Drive, direct spur-geared to machine.
Ditto, running light...	5	1·48	...	

In the above list the amount of power consumed by the machine is shown, also the actual power consumed in doing useful work.

Mr. Aitken.

crane-load is very considerable, in comparison with the machine and lighting loads, it is advisable to run the lights off a separate generating set. Fig. A. shows a tracing from recording ammeter card for 24 hours. The sudden fluctuations are caused by the stopping and starting of the electric travelling cranes, which are of the three-motor type and for six-ton loads.

With regard to polyphase working, the variations in speed and torque in an engineering shop are so great that one is compelled to decide in favour of the continuous current, in spite of the inconveniences of the commutators, until such time as the polyphase motors can be made to do what continuous-current motors will do.

Mr. Andrew Stewart.

Mr. ANDREW STEWART (*communicated*): The comprehensive nature of up-to-date electrical engineering makes it difficult to give the specialist in one particular branch of the industry a very frequent innings; considering the importance of electric motive power, the papers which have just been read on the subject will put on record much that is valuable. Mr. Chatwood's preference for direct currents must, I fear, be due more to a lack of acquaintance with multiphase currents, than to any disadvantages which are inherent in them; certainly the cases which he cites, are those in which constant *not* variable speed is required. Under these circumstances, surely the author will not argue that direct currents have any advantages over alternating; indeed the latter are just the proper thing in the cases under consideration. That the author should condemn the adoption of four motors in preference to one, because on paper a balance of 2¾ per cent. per annum can be shown in favour of the latter is, one might think, a little dogmatic. There might easily be collateral advantages which cannot often be accurately expressed in £ s. d. that would overbalance the small difference; if part of the works made even a very small amount of overtime, judicious grouping to several motors would easily turn the balance in favour of more than one motor.

The glimpses which we get of the efficiency of some modern direct-current motors, is a striking commentary on the result of unlimited competition; the motors may be mechanically strong, but what engineer who has been engaged in testing them can say that equal progress has been made in efficiency? Of course the idiosyncrasies of the purchaser have had something to do with this; people seem to want a motor which is as invulnerable as a modern ironclad, and with as little hum as an empty beehive, yet as cheap as possible; something must be sacrificed, and efficiency is frequently offered as a sacrifice to the other and more desirable (?) features.

Mr. Williamson gives us a paper which from a practical point of view could scarcely be beaten. To the man who installs large power plants many of his deductions are not new, while others permit of different views. Not every one has been so fortunate with chain-drives as the author seems to be, but the performance of these are chiefly governed by environment; there are many cases where they may be employed in place of worm or double-reduction spur-gearing, though where the ratio of reduction and space permits, single-reduction spur-gear would be hard to beat. There are, however, cases when it seems

Mr. Andrew Stewart.

reducing gear is scarcely justified at all. Take cases where moderate speeds of 500 to 650 revolutions per minute are required, and horse-powers of 5 to 10 or 15. In how many cases can one find high-speed motors with spur-gear used, even where considerations of space are not paramount? Taking motors of the aforementioned horse-powers and comparing slow-speed motors of 600 revs. against high-speed motors of about 1,300 revs. with spur-gear, the efficiency is in all cases about 6 per cent. in favour of the slow-speed motor, while the capital cost is only 10 per cent. in favour of the geared motor. Considering that a 15-H.P. motor using energy at 1d. per unit can in a year take electrical energy to the value of twice its capital cost, the small extra interest charge involved in the slow-speed motor is saved from 8 to 10 times over in a single year; yet how many examples of geared motors can be found, with nothing except lower capital cost to justify their existence.

The variable-speed motors which the author mentions on page 937 are not by any means new, but the limit has hitherto been set at much less than 100 per cent. increase, due chiefly to sparking difficulties. Perhaps he can tell us if commutation takes place under a pole horn maintained at constant strength by some means; it does not appear likely that satisfactory commutation can be obtained without some special commutating device. The switch Mr. Williamson mentions does not seem to present any difficulty, and has been used for this purpose before; the patentable features should certainly prove interesting to the men who have for years been engaged on problems connected with speed regulation.

The crane speeds which the author gives are of more than academic interest; nothing is more conducive to economy in engineering and shipbuilding yards than the rapid handling of heavy weights. Who in charge of a shop has not seen expensive machines, almost equally expensive skilled workmen, and a small army of labourers idle, while a steam or rope-driven crane crawled down the shop with the work? Such a spectacle never fails to raise the back of an employer, and by directing attention to this aspect of the question, one is more likely to succeed in convincing works owners of the advantages of electricity than by means of the mathematics which Mr. Chatwood has inserted in the closing pages of his paper.

The question of a spare plant in a works generating station is raised by Mr. Williamson, and it is remarkable how central-station practice has stamped itself on many installations. It may be questioned whether, in many works, the outlay of 20 per cent. of the capital on spare plant can be justified. The works owner must first of all be convinced that electricity is quite as reliable as his old plant, and if he is told that a certain proportion of his generating plant has to be in duplicate he will not feel reassured. He argues, not unreasonably, that he does not at present duplicate his boilers and engines, and cannot see, if electric power is quite as reliable, why he should put in spare generating plant. Many works get along quite well on no spare plant; I have been connected with several works plants from 200 to 1,000 H.P. where no spare plant has been installed, and in two cases six years' running has not yet shown that any risk was involved in

dispensing with the spare plant, even where in one case a night and day shift is the rule: such repairs as have been necessary in the generating station have been executed during week ends and holidays, just the ordinary factory routine. Mr. Andrew Stewart.

The table of costs per unit emphasises what has been recognised by engineers engaged in power work, viz., that no plant over 200 H.P. can afford to buy its energy; wholesale power generation is cheap, but it costs too much to deliver it at the factory. Capital charges on mains and sub-station plant unduly burden the large undertaking, while the losses in transmission and transformation have also to be reckoned with.

A works of any size can purchase coal almost as cheap as the large generating station; it can put down its generating plant at almost the same cost per kilowatt, and if it does not generate as cheaply, the difference is only a very small fraction of a penny per unit.

Mr. H. O. WRAITH (*communicated*): Mr. Chatwood gives tables stating the maximum brake-horse-power required for certain tools, but these figures do not really give any useful information, for so much depends on the feed and speed, that is to say on the amount of metal removed in a given time. Only within the last week I was in communication with a firm (not electrical engineers) who had been inquiring for large lathes, driven by separate motors, and the sizes of motors quoted for by various toolmakers varied from 4 H.P. to 120 H.P., for what was nominally the same lathe. The reason for the discrepancy was that the firms quoting low-powered lathes were offering machines which would only remove perhaps one-tenth of the metal in a given time that the higher-powered lathes would. The firm offering 120 H.P. made no mistake about being able to do the work required. Mr. Wraith.

It would be interesting to hear if the author of the paper has taken any tests on the basis of measuring the actual work done by the machine-tool. I think the figures the author gives as to grindstones used for dressing, etc., are, for this class of work, rather low, and I should be sorry to put two great hulking seven-foot grindstones used for these purposes on one poor little 15-H.P. motor in a shop where any attention is paid to getting work out quickly, and therefore cheaply. It is the usual thing for the grinder, when dealing with long bars, to sit on the bars when grinding, so as to get more weight on, and I have often seen a single grindstone take 13,200 watts, or roughly 15 H.P., when grinding bars, say, two and a half inches wide.

The method of starting grindstones and similar machinery with heavy moving parts by means of a magnetic clutch is very ingenious, but has Mr. Chatwood any experience as to the wearing qualities of such a clutch? for my experience of clutches is that the cost of renewals, adjustment, and repairs more than overbalances their advantages. It appears to me that a simpler and better method is to have a shunt motor with a few series-turns on, a starter of some form that is not likely to take any harm from being overloaded now and again, for preference perhaps a liquid starter, and see that the man who starts the motor knows what he is doing, and starts slowly. The arrangement the author proposes is very susceptible to injury in incompetent hands, more so than the simpler arrangement above, where about the worst a man

Mr. Wraith. can do is to blow the fuse, and, unfortunately, in the majority of places it is very difficult to keep electrical machinery out of incompetent hands.

Mr. Chatwood recommends the use of storage batteries in private stations of considerable size. Has he any figures in support of this? The difference between the ordinary day-load and, say, overtime load may be great, but in an installation of any size the percentage of variation of load during ordinary working hours is very little, and if the installation has been properly designed, the generating plants are of such a size as to fit in with the different loads at different periods of the twenty-four hours, so that whatever generating plant is running, is running as near as possible to its maximum and therefore most efficient load. The battery is only occasionally useful and economical, on small overtime loads, and taking into account its heavy first cost, space it occupies, and large depreciation, I think there is no doubt, in nearly every case, it is not worth putting in, and that it is cheaper in the long run to keep an engine running for overtime, except perhaps in the case of offices, which hardly come under the head of machine shops, or where there is a lot of Sunday repair work done, which would necessitate, in the absence of a battery, firing up a boiler. Such places where Sunday work is done are, however, few and far between, and in such cases a better solution of the local problems would probably be found in a gas-driven plant.

Mr. Chatwood. Mr. A. B. CHATWOOD (*in reply*): Before I reply to one or two points made by speakers in the discussion, I should like to congratulate Mr. Williamson, first on having had the opportunity of dealing with works such as those described in his paper, and secondly on having had the unselfishness to give us experimental results such as he has done in his paper, of which I do not think we can fully appreciate the value here and now. It is in the months to come that we shall find out how valuable they are, when we use them constantly for reference. On pages 934 to 936 of Mr. Williamson's paper he speaks of the driving cost differences with various groupings of a certain number of lathes, and he says the working conditions would be fairly represented by assuming eight out of ten machines to be in use, the remaining two having tools or work changed or set. Unfortunately my experience has not lain in shops where that statement would be at all true. The probable working conditions in these shops are that about two tools out of ten would be working, and the advantage, therefore, in those cases of a divided drive would be very much more pointed than is shown by Mr. Williamson. Mr. Allen has explained to us a method of driving which, personally, I had not come across to any extent, but I think that in the bulk of small shops the 25 per cent. which he put down as a saving would be a long way off the mark, because the abolition of counter-shaft arrangements and belts off the line shaft would, I think, cause a saving of very much more than that—at any rate, in shops such as I have been speaking about. Mr. Scott called attention to a matter that is mentioned I think, in both the papers that were read—that is, to the use of a flywheel or a very large armature. I do not think that its importance can be very much exaggerated in some cases with reversing machines and with machines with intermittent load. He also

spoke at some length on three-phase plant, and Mr. Patchell made some remarks about it. I have been for the last two or three months carrying out experiments in a cotton mill in order to determine a good many points that never have been determined as far as one can find out, about driving cotton machinery electrically, and I think I may say that in all probability the mill is going to be driven electrically. It is a small Bolton mill of 125 H.P., and one of the great objects of going in for the conversion to electric driving is the doing away with all the bother of having driving plant of any sort to look after. The Corporation of Bolton can supply either single-phase alternating current or direct current. This mill, I need not say, will be driven by direct current. At the same time, I have no doubt whatever that if electric driving spreads into the cotton mills of Lancashire, three-phase plant will be put down, and I think very likely some go-ahead towns—such as, perhaps, Bolton—will go in for supplying three-phase current specially for mills at a price considerably under a penny. But I do not think that three-phase motors are universally applicable for driving machine tools. One of the very great advantages of electric driving is the question of delicate speed control, and of not being compelled to jump from 200 to 400 revolutions, or from 400 to 800 revolutions, or anything of that sort. Personally, my experience with polyphase motors is that up to the present they are certainly deficient in speed variation. Mr. Scott advocated the use of long cones and belts to get over the difficulty of delicate speed control with the polyphase motor, and he said that belts were good enough for our grandfathers and they were good enough for our fathers, and I understood him to infer that therefore they are good enough for us. I think the object of having papers at this Institution is to advance a little on what our grandfathers did. I do not want to say very much about our grandfathers and fathers; they were very good people in their way—at least mine were—but I have spent some eleven years in connection with works where that principle was carried out, and I must say that, as far as one's work was concerned, I never had such a miserable time. Mr. Scott also spoke about armatures burning out. I have had experience of a good many motors, and I have had, in machine-tool driving, one case of an armature being burnt out. I was not very much surprised about it, because it was a motor that I built myself for experimental purposes about fourteen years ago.

Mr. Chatwood.

Dr. Rhodes has somewhat mistaken the view I attempted to express at the end of my paper on the question of generating current. I most cordially agree with him in saying that where the demand is large it is better to generate one's own current. The point which I wanted to enforce in my paper was simply, that if you can purchase current from an outside source as cheaply *or nearly so* as you can produce it yourself, then it is better to save the worry of having another department to look after and devote the portion of your energies thus saved to increasing your own particular business. I do not think that in any of the particular cases given in my paper, especially as none of these shops have any electrical people at present, Dr. Rhodes would advise generation on the premises.

Mr. Chatwood.

I can quite believe Mr. Wraith's statement as to the various powers quoted by tool makers for the same lathe, as I have experienced a case in which the tool maker who built a machine stated that a 6 H.P. motor was big enough for it; a 40 H.P. was put upon it, and this has been replaced by a 60 H.P. Quite apart from this ignorance of some tool makers, the cutting power of what is nominally the same lathe by different makers varies enormously.

Tests of the nature suggested by Mr. Wraith hardly come within the scope and object of the paper, which was intended rather to point out what is actually taking place in connection with electric driving installations of small shops carried out by men absolutely ignorant of the subject, and to point out some, at any rate, of the numerous factors which should influence the arrangements of any particular case. I can, however, give the figures obtained on a 6-inch lathe during the course of some experiments which I carried out on various samples of steel: but I should not like any one to expect a result anywhere near this in ordinary practice, as the circumstances were here entirely special.

The steel cut was 1 in. diameter bright drawn bar, cutting speed 50 feet per minute, tool $\frac{3}{8}$ths round silver steel very carefully treated, held in a Smith and Coventry holder, cutting angle 55° 15′; front clearance 7° 55′. Rate of cutting, 22·84 lbs. per hour. Power absorbed at tool point, 0·314 H.P.—equivalent to 72·6 lbs. of steel removed per hour per H.P.

The grindstones referred to in the paper are not used with the object of removing as much metal as possible, but simply for removing rust and scale and for dressing small rivet heads: the powers given in the paper have been obtained from actual practice. Where, however, stones such as these are used for heavy work, as is the case in the manufacture of textile machinery, the power absorbed will sometimes surpass the figures given by Mr. Wraith.

Mr. Wraith is, I think, under a misapprehension as to the magnetic clutch. The arrangement described, somewhat imperfectly perhaps, is not a mechanical clutch magnetically operated, but entirely magnetic, the two parts of the clutch being separated by a fixed small air-gap, so that there is in the clutch itself no wear.

I must flatly contradict Mr. Wraith's statement that I "recommend the use of storage batteries in private stations of considerable size." In small shops such as those described in the paper the fluctuations of load are considerable—from 2·5 to 9·3 H.P. in one case, from 4·6 to 23·6 H.P. in another. The statement in the paper is, I think, rather a reminder that it is desirable in each particular case to consider whether or not batteries would be advantageous. So many local circumstances enter into the matter, that it would be impossible to form any general opinion.

Mr. Andrew Stewart seems to have read the paper somewhat carelessly, as in the three cases cited specificially, pages 979 and 980, as well as in the summary of the possible advantages of the installation of electric driving, page 971, the advantage of variable speed is sufficiently insisted on. I expressly stated, however, that in my opinion there was no general question of alternating and continuous current, but that every case must be decided on its merits.

I should like to point out that I did not condemn four motors instead

Mr. Chatwood.

of one in Case 2 because of the slightly increased cost, but because "almost the whole of the shafting is to be driven and no one of the advantages of electric driving is to be secured," and at the same time pointed out that the cost would be slightly higher.

May I refer to the diagram given in the paper with regard to two planing machines, as I think an analysis of them will give a clear idea of what goes on in shops such as those discussed in my paper. The power absorbed by the smaller machine when not actually cutting is considerably greater than that absorbed by the larger, although the speeds are slower, showing that the condition of the smaller machine is such as to require examination. It is hard for men trained in up-to-date shops to realise the conditions which prevail in shops which were all right thirty years ago, but which have not advanced in any way since.

I should like to feel that we, both as individuals and as an institution, are doing all we can to influence manufacturers and their managers to consider carefully every case of electric driving, and not to follow the policy which has been followed in the shops noticed in my paper, a policy which can only be described as "the shove-a-motor-down policy."

Mr. Williamson.

Mr. A. D. Williamson (*in reply*): I thank you very much indeed for the very kind remarks that have been made about my paper; I think almost too much has been said in that direction. If the paper is of value, it is simply due to the fact that I have been in the position to accumulate useful information. Now with regard to the discussion, the first point raised was the question of breakdowns. I have thought about it, but I cannot remember any serious breakdowns whatever. We have had to stop occasionally—possibly for a hot rod, or something of that sort—but dividing the plant in the way I have mentioned in the paper, we have always had some spare plant to carry on, and it has caused no stoppage of the works. If we had any trouble at all, it has been not with the electrical plant, but with the steam plant—with the boilers. I do not think the comparison between the large marine engines and electric generating plant is quite fair, because a steamer has to have one large engine—there is no help for it. If that breaks down, the ship is stopped. That large engine is always working at maximum load, and therefore at maximum efficiency. But if we put one large engine into a works, that engine would have to work sometimes at only one-tenth of the full load, and therefore at very poor efficiency. So the two cases can hardly be compared.

I do not quite follow Mr. Mavor's statement that the real argument for adopting electric driving is "the possibility of introducing economical plant into the generating stations." I think rather that the centralisation of the plant is the main argument. Whether the plant be old or new, economical or wasteful, within reasonable limits the cost of labour will not be altered. Coal and water are reduced by economical engines, but these two items only represent about half the cost per unit at the switchboard.

The economy of electric driving must be considered in terms of useful work at the machines and tools. Replacing an old and inefficient engine which drives direct to line shafting, by a new engine of high

Mr. Williamson.

efficiency and a dynamo and motors, will not reduce costs so long as the load remains high. It may, however, have a very marked economical result if the load is a varying one and full advantage is taken of the opportunity to cut out shaft and belt losses at times of light load.

There can be no general argument for or against electric driving; each case has its *pros* and *cons*.

I do not mean to suggest that economical engines should be passed over, but I attach more importance to careful attention to the arrangement of machine driving together with absolute reliability in the generating station.

I quite agree with Mr. Selby Bigge. He says that the power-house should be designed in proportion to the whole area of the works—that is, to leave room, as I understood him, for all the generating plant that is likely to be required at any time. That is what we tried to do. We have not only extended the shops, but we have also bought more land—when the first power-houses were planned, nobody could foresee that. The method of allotting space for power-house in recent cases was to take the total acreage of the land, and from the figures which are published in the paper to estimate what is the maximum amount of power required to drive all the machines which we could put into the buildings covering the whole of that ground. Those figures in the paper will be found fairly accurate for works of a similar nature. It is not always possible to get as much space as one would like in a central position to put down the plant. That is why we had to divide it and to have two or three separated stations. Then about the insulation on the overhead wires. We provide a light insulation, as I say, chiefly for the protection of the telephone wires, which have an unfortunate habit of falling, and when they come across the power wires there is trouble and the telephone service is interrupted. After six years we find that none of the light insulation has come off the wires, and it is apparently in a perfectly good state of preservation. The recent machines which we have put down, within, say, the last year or two, are nearly all designed for variable speed. It is becoming much more common now than it was to have variable speed. I think that is chiefly due to our having found out the extreme convenience of it. I have spent a good deal of time looking about for alternating-current motors which possess the quality we have been hearing about of a large range of speed variation, but I have really never come across a practical solution of that difficulty yet. I have been in most of the Continental electrical works and manufactories, but I have never come across a case which was seriously described as a practical solution of the difficulty. I am very pleased to find that every speaker has agreed on the question of circuit-breakers. They were a constant source of worry to me at the works, fuses with a liberal margin are very much better. As regards saving in the works, Mr. Selby Bigge put it down roughly at 35 per cent. Curiously enough, I have worked out a number of cases where I could get fairly reliable data, and I came to exactly the same conclusion that it was between 30 and 40 per cent. You may take it as 35 per cent. on the average when you are dealing with works of this nature. When we started to put down this plant, we had to choose between

alternating and continuous current. Of course, at that time there was very little comparison between the two. Mr. Williamson.

There is no doubt that improvement has been made in alternating motors, but I do not think that they compare for our class of work—for solid engineering work, where you want a very heavy starting torque in the case of cranes and shop machines with flywheels, which take a great deal of starting, and also with machines requiring speed variation. I think those two points are most important, and I fail to see where the advantage of 3-phase work comes in when you are dealing with short distances, and where, if you use 3-phase plant, you would not exceed the pressure which you use for continuous. I think it is a positive disadvantage, because, if I had 3-phase machinery in the works, I should feel tempted to put transformers in, in order to get two or three different pressures, and by doing so, of course, would throw away a certain amount of energy. I agree with Mr. Allen entirely on the question of clutches. We have used clutches in a number of cases and found them exceedingly good, but six or seven years ago we had a difficulty in getting them. Mr. Fairfax spoke of the speeds we have chosen. We had to choose those speeds, averaging about 600, as a compromise between the excessive cost of low-speed motors and the difficulty of reducing high-speed motors down to the point where you would wish to use the power. This is a very interesting gearing indeed which he has brought forward to-night, but I am afraid that to get only a difference of speed of from 800 to 650 on four pulleys side by side would not meet our requirements in all cases. This model seems to run very nicely, but for most tool operations we require a much wider range of speed. Mr. Russell, speaking of the Silvertown Company, says there are a number of cases where it would not do to put in motor driving and displace engines which are there at present. I quite agree with that in general. In many cases there are operations which are much more economically done by steam-engines, taking into account the capital outlay involved in electrical driving arrangements. In our own works we started with that idea and modified it a great deal, because we found that by putting on every machine at all suitable for electric driving, we increased the load on the generating plant and secured a steady demand for the current, thus reducing the cost *per unit* very considerably all round. When a fresh operation was put on to the power plant, although it might not be done any cheaper than it was originally, yet by increasing the load at the generating station, and dividing the standing charges between many more units per annum, we found it cheapened the cost of production on all the other operations about the works. In considering the cases of applying motors to a works like the Silvertown or any other works, it is very important to take into account whether labour can be saved or not. It is a question of reducing the staff of engine-drivers and firemen to a great extent. It is not so much a question of an isolated engine as of an isolated boiler—that is the trouble that has to be got rid of. With regard to the worm-gearing which is used in the Silvertown works, I have had experience of fairly heavy power worm-gearing under exactly similar circumstances—that is, in indiarubber works. I had tests made there

Mr. Williamson.

of it, and the efficiency came out between 85 and 90 per cent. Ball thrusts were used, and of course it was fairly modern gear, very well made and running in oil, and it had a long life. There was absolutely no fault to find with it for that special work. It is too expensive for ordinary work, I think, and not quite as efficient as spur-gearing. I quite agree, also, that chain-gearing costs at least 50 per cent. more than spur-gearing, but it has so many advantages that I think it is worth paying for it in many cases, in order to get a compact drive.

I did not mean to speak disparagingly of smooth-core armatures, because we have five or six smooth-core machines now of about 250 horse-power, and though they have been running for six years they have not cost anything at all for repairs. But as we can buy slotted armatures for much less money than we gave for these old smooth-core machines, I much prefer to have slotted ones, because they are undoubtedly stronger. In the early days I had a number of cases of the armature conductors being swept round the face of the core, in smooth-core motors, subjected to heavy variations of load. We have had no troubles of that sort with any generators, though in the six years we have had them they must have had a good many short-circuits. Coming to Mr. Scott's remarks, my experience is practically confined to continuous currents, and I have done very little with alternating currents; but as far as my continuous-current experience goes, it is totally different to Mr. Scott's. We do not have to continually renew carbon brushes, and we are practically unaware that there is a commutator on the machine—it gives no trouble. There is one point that Mr. Scott raises, and that is the comparative space occupied by the continuous- and alternating-current motors. Mr. Scott says you can put an alternating-current motor in a space into which you could not get a continuous-current motor. Does that include the speed cone that Mr. Scott recommends for varying the speed? I should think probably not. The question of gas-engine plant was mentioned. It is only recently that we have been able to get a big gas-engine. We are adding some gas-engines now, and if we had work to do again of a similar nature we should put in gas-engines without a doubt. We are at present building some very large generators for a works in Glasgow, which are to be driven by gas-engines at slow speed. When the plant is big it pays to put down Mond gas plant, but if you have got a small plant it does not pay. To reap the full benefit of all the bye-products in connection with the Mond gas plant you must have a fairly big plant to deal with. Mr. Hammond mentions the high consumption of coal. That has troubled me a great deal, but I cannot help it. Those are the figures. I think it is partly due to having small sets, and then in the case of the North Power-house we are non-condensing. Another way I account for the high cost is that we have steam-driven auxiliaries—the feed-pumps and the condensers being driven by steam. There is no doubt that these small auxiliaries when they are steam-driven eat up a great deal of steam, and steps are being taken at the present time to replace this steam auxiliary plant by electrically-driven plant, and when that is done I am pretty sure that we shall get this objection removed.

Mr. Williamson.

I do not think that the load-factor plays such a very important part in fuel-cost. Consider the two cases of a perfect load-factor and that at the Sheffield Works. The first would be represented by a continuous electro-chemical process when the steam consumption would be steadily at its minimum, say 15 lbs. per B.H.P. hour for condensing engines of 500 B.H.P. The load-factor at Sheffield is of such a nature that we can only run generators up to, say, an average of 75 per cent. of full load, allowing a margin for fluctuations in demand. Our steam consumption would not be more than 16 lbs. for the same size of unit. This difference is only about 6 or 7 per cent., and would only raise the coal per unit from 0·3d. to 0·32d. To go further, lighting stations have a far worse load-factor, but their sets do not usually run at a lower mean load than 75 per cent., so that during the time they are on they work as efficiently as the sets in the steel works. No doubt some additional loss is made in lighting stations, by having to light boiler fires and keep them banked waiting for load, but my point is that load-factor affects coal consumption very little, while it affects wages and standing charges largely.

The calorific value of the coal used at Sheffield is 12,720 British Thermal Units, this being a mean of five kinds of coal.

Replying to Mr. Stewart's question as to the means adopted to secure sparkless commutation with weak field, I may state that no special form of pole-tip or commutating device is used; the main principle of design is to make commutation as natural and easy as possible. There is no question that perfect commutation is secured over the ranges of speed mentioned, and that with very little addition to the weight compared with a constant-speed machine whose speed is, say, midway between the maximum and minimum of that of the variable-speed motor.

Mr. Stewart is right in saying that variable-speed motors are not new. I have used them for six or seven years, although it is only within the last four years that I have made full use of the convenience of variations of 200 or 300 per cent. in speed.

Mr. Chatwood says he thinks that two machines working out of ten would represent working conditions more fairly than eight out of ten. If we found that to be the case in our works, we should look out for some new foremen.

The President.

The PRESIDENT: We have certainly had very interesting papers from both these gentlemen; they are papers which I think do an Institution like ours a great deal of good, because they teach the outside world what they ought to know—viz., that electrical current can be used to great advantage in many cases where the public may think its adoption of doubtful utility. It is quite needless, after the full and interesting discussion that has taken place, for me to say anything, because I can see by the way that you have listened to the remarks of Mr. Williamson and Mr. Chatwood, and also to the gentlemen who have discussed the papers, that we are very much indebted to them for what they have done for us. Without further words I ask you to show your appreciation in the usual manner.

The vote was carried by acclamation.

THE RICHMOND-CAREY LIFT.

The PRESIDENT: Before you go, gentlemen, I have to say that Mr. Carey has been kind enough to bring here a model of the Richmond-Carey electric lift. The time at our disposal is now very short, and there is no paper to be read on the subject. Mr. Carey, in making his demonstration of the working of the lift, will give us a short explanation which will only occupy five minutes.

Mr. R. F. CAREY: The lift of which the model is before the meeting is a new electric lift which I have got out in conjunction with Mr. Richmond. The idea of it is to do two things—first, to get a lift which will work automatically, and, secondly, to get one which, as far as we can see, is absolutely safe. I do not know whether any one can point out how it is possible to have an accident with it. I have tried to find out, but cannot do so. There are no attendants required. No one can open the outside doors and fall down the well-hole, because the doors can only be opened when the lift has come to a standstill on the particular floor. That avoids the most frequent cause of accidents. By pressing a button the lift comes automatically to the required floor, stops, the door is freed, the passenger steps in, and, by pressing one of a series of buttons inside the car, directs the car up or down to the floor to which he desires to go. There the same process is followed; the car stops automatically, the door is unlocked, and the passenger steps out. It is worked in the ordinary way by an ordinary motor and gearing.

Mr. Carey then showed the model in operation and explained a diagram which he exhibited.

The PRESIDENT: I am sure, gentlemen, that you wish that I should thank Mr. Carey in your name for bringing this lift before us.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:—

Associate Members.

William Alfred Barnes.
Joseph Wm. Aberdeen Binner.
William Dolton.
Henry Francis Francis.
Joseph Menmuir.
Albert Edwin Moore.
Geo. Richardson.
Arthur Robert Shapley.
Herbert Vickers.

Associates.

Cecil Edward B. Christie.
Chas. E. F. Evans.
Wm. Hellier Evans.
Robert Pries.
Samuel Scargill.
James Stephen Souter.
Percy Alfred Spalding.
Herbert James Stracey.

Students.

Richard Chas. Hope Dawes.
Henry Arnold Greaves.
Wm. James Lindsay.

LEEDS LOCAL SECTION.

ELECTRICITY SUPPLY FOR SMALL TOWNS AND VILLAGES.

By A. B. MOUNTAIN, Member.

(Paper read at Meeting of Section, March 19, 1903.)

The success which has attended the introduction of electricity to all large towns is indisputable, and that it is being adopted for lighting and motive power at an ever increasing rate is also undeniable, but when we consider the small towns and villages we find very little progress has been made, and when we think of the immense number of such places, many without even a gas supply, we must realise that there is still a great field open to the electrical industry, but the fact that so little has been done shows that difficulties and misconceptions exist which are tending to impede the introduction of electricity, and it may be well to consider these, first, from the point of view of influential gentlemen residing in such small towns, whose support is necessary for the introduction of any new undertaking, and, secondly, from the engineers' point of view.

The first difficulty is the want of enterprise or energy which is noticeable in all small places, not necessarily due to want of knowledge, but rather to a desire to leave things as they are. This feeling of apathy is greatly encouraged by the local gas companies, who are, perhaps naturally, in opposition to the rival undertaking, and do not yet realise that the introduction of electricity nearly always leads to an increased consumption of gas.

The second difficulty is the supposed large initial outlay of capital necessary to construct works, the very general idea that such small works must charge a high price per unit, and so cannot compete successfully with gas or oil, and will therefore not be carried on profitably, and will consequently, if owned by a company, pay no dividend, or, if owned by the local authority, become a burden to the ratepayers.

It is perfectly true to say that several small places in which works have been constructed have not been financially successful, and that care must be exercised in the designing of the works and mains to ensure success. The causes of failure would appear to be due to the small towns constructing works upon the same lines as neighbouring large towns, or, in other words, such failures have been due to want of knowledge, but with care in the selection of a system and in designing the works and distributing mains financial success can be assured even on the smallest scale, and the initial capital outlay upon works in a small place should be proportionately less than in a large town where one is compelled to construct works and lay mains of sufficient size to meet the demand which is certain to arise in future years, and which

necessitates a large proportion of the initial capital being unproductive for some years. Then, again, it is wrong to assume that small works cannot sell electricity profitably at a reasonable price per unit. In many small places, both under the control of companies and local authorities, the charge is at the rate of from 4d. to 6d. per unit, and, in some small villages where the supply is derived from local works such as collieries, mills, local electrical engineers, etc., the supply is being given at prices varying from 3d. per unit upwards, and in many cases, where the supply is being taken from the gas or oil plant installed for a private residence, a charge of 4d. per unit would be profitable.

There is also the further fact that the charge for gas in small towns is usually much higher than in large ones, so that the electricity supply would have this great advantage in small places. It is usually found that electricity at 4½d. per unit will be adopted in preference to gas at 2s. 6d. per 1,000 cubic feet.

The third point against local enterprise is the idea that the power companies will eventually supply all such small towns and villages, and will consequently ruin any local undertaking. Undoubtedly, during the last three or four years, a great deal of discussion has taken place, and the idea has been very generally spread that the power companies contemplate supplying over the whole of the areas for which they have Parliamentary powers, but this does not seem probable or possible, commercially, if one considers their past achievements, and the fact that the small villages and towns are so far apart that in most cases the mains required to connect two places will exceed the cost of constructing and working a generating plant. In fact, it is difficult to see what advantage can be gained by taking energy in bulk from a power com-company. In any case consumers will require meters and services, mains will require laying from some central point to such consumers, a building must be provided into which the mains would be carried, and in which the alternating motors and continuous-current dynamos will be fixed. This practically covers all that will be required for a local central station, with the exception that steam, gas, or oil engines would be substituted in place of the alternating motor; in both cases practically the same supervision and labour would be necessary. The difference in cost would be that energy from the power company would probably, in accordance with the latest published information, cost 2½d. per unit, whereas it could be generated by steam or oil engines at from ½d. to 1d. per unit.

The fourth and perhaps most usual difficulty is the cost of obtaining the necessary Parliamentary powers to establish local companies or municipal undertakings, and a further dislike to the stringent regulations of the Board of Trade and the Local Government Board. These difficulties appear to affect municipalities more seriously than companies, but in any case are not such as to cause any trouble when the works are once started. The fact that the Local Government Board will not allow the cost of obtaining a provisional order to be placed to capital account necessitates a charge upon the rates, and the additional fact that the repayment of all money borrowed must commence at once is a very serious point, and greatly retards new works, because it is practi-

cally impossible to get sufficient consumers connected during the first year to bring sufficient revenue to provide the amount required to repay the first annual instalment of capital; consequently this amount, if not provided by revenue, must be provided by rates.

That some concessions on this point might be made by the Local Government Board is generally agreed, and when it is considered that in the case of tramways one or two years are allowed for construction, and that the full revenue from a tramway system commences at once, whereas the revenue from an electric supply undertaking can only grow gradually, it will be agreed that local enterprise is not encouraged.

Engineering Difficulties.

In considering the supply of small towns and villages from the engineers' point of view, it is necessary to try and gather what small amount of data exists, and consider the problems as quite distinct from the supply of large towns.

The expression "small town" should include any place having a population of from 5,000 to 15,000, and "villages" any place having a population of from 500 to 5,000.

There are in Great Britain and Ireland about 500 such small towns, and between 2,000 and 3,000 villages, and very few of these have any electricity supply undertakings, so that there are plenty of opportunities for activity in developing local enterprise.

The chief points which we, as engineers, should determine to enable us to design a small scheme upon sound financial lines are:—

1. The probable number of consumers and consuming devices which will be connected within two or three years, and the ultimate maximum development.

2. The maximum demand which the generating plant will be required to supply.

3. A suitable position for the generating station, the form of motive power and system of generation.

4. The best method of distributing the supply, and the connection of consumers.

The first point is by far the most difficult, and nothing but experience will enable one to estimate at all correctly, but it is most important, because the works should be constructed so that extensions do not mean scrapping plant in future years, and on the other hand the works must not be unnecessarily large, or the financial results will be unsatisfactory during the first few years.

It is also quite impossible to form any correct idea of the consumers who will be connected without first settling the price to be charged; obviously, the lower the price, that is to say, the better the price compares with gas, the quicker will consumers become connected, but this course will also probably result in a loss for the first year or two. There is little doubt that it is advisable to fix the price as low as possible at the start and encourage all classes of consumers.

One method of ascertaining the number of consumers likely to be connected is to graduate the number of premises by their rent or

rateable value, and it will usually be found that the majority of premises rated above a certain amount may, with a few exceptions, be relied upon; the amount selected will vary in proportion to the size of the town. If, however, the electricity supply is in the hands of a company which would adopt some system of fixing prepayment meters and a few lights free of cost, it might be possible to connect a very large number of small consumers. Unfortunately a local authority has no powers under the Electric Lighting Act to charge to capital the cost of fixing wiring upon consumers' premises; some of the larger towns have obtained powers by applying to Parliament, but this course would be altogether too costly to be undertaken by a small place.

The second point is more easily determined. In small places shops do not indulge in a large amount of show, and fewer lights are fixed generally. The maximum demand upon the works would not appear likely to exceed, during the first two or three years, half the lamps connected, and this would gradually be reduced to about one-third of the total lamps connected; this is assuming that electricity is used for street lighting—if not, the maximum demand would be reduced.

The third point, the selection of the form of motive power, has in many cases given the author considerable trouble.

The selection of a site for the generating works is not difficult, if one first decides upon the kind of motive power to be adopted. If steam is to be used, it is necessary to bear in mind facilities for getting in coal, and water should be as near as possible for condensing purposes. If gas is to be used and the supply taken from an existing company, the position of the site must be such that the supply of gas may be easily and cheaply obtained. If, however, it is thought advisable to make your own gas or adopt oil engines, then the site may be selected in the very best and most central position.

In most small towns the disposal of refuse is becoming a more or less serious question, and should have consideration in conjunction with the supply of electricity; this may influence very largely the selection of the form of motive power to be employed, because if Refuse Destructors are to be adopted the heat may be used for generating steam, and the cost of destroying the refuse reduced by the amount which will be paid for the steam used for producing electricity. The steam thus economically produced is of great advantage to the electricity department, as it enables a low charge to be made for energy for motive power purposes.

The form of motive power to be adopted must therefore depend upon local conditions to some extent. The chief point to determine, however, is with which form of motive power the most economical generation of electricity may be obtained, and it may be interesting to give some examples of the different kind of plants which may be adopted for a small town with a population of about 7,000.

The estimated lamps connected during the first two years are 3,000 of 8 c.p., and the estimated connections at the end of about the 10th year 14,000 of 8 c.p. The first instalment of plant would therefore require to be equal to about 60 kilowatts, and might be

divided into one 20 kilowatt and one 40 kilowatt plant; the latter sized unit of plant being continued as the station developed.

Confining now our attention to the generation only, the works would cost the following amounts, depending upon which form of motive power was selected:—

OIL.

	£
Buildings and foundations...	250
Two engines, dynamos and switchboard	1,175
4 H.P. plant instead of accumulators	125
	£1,550

TOWN GAS.

Buildings and foundations...	250
Two engines, dynamos and switchboard	1,050
4 H.P. plant instead of accumulators	100
	£1,400

PRODUCER GAS.

Buildings and foundations...	500
Two engines, dynamos, switchboard, and producer...	1,375
Accumulators	175
	£2,050

STEAM.

Buildings and foundations...	750
Two engines, dynamos, switchboard, and boilers ...	1,475
Accumulators	175
	£2,400

For the purpose of ascertaining the average cost of generation it may be safely assumed that in the second year 30,000 units of electricity will be sold. The costs will therefore be, approximately, as follows for each form of motive power:—

OIL.

Oil, used as fuel	·5 pence per unit
Oil, waste and stores	·12 ,,
Labour in the station	·40 ,,
Repairs	·20 ,,
Management, rents and rates ...	·37 ,,
Depreciation, at 4 per cent. ...	·5 ,,
Interest, at 4 per cent.	·5 ,,

Total cost of generation per unit sold, 2·59d.

Town Gas.

At 2s. per 1,000 cubic feet, allowing 25 cubic feet per unit.

Gas	·6 pence per unit
Oil, waste and stores	·12 „
Labour in the station	·40 „
Repairs	·20 „
Management, rents and rates ...	·37 „
Depreciation, at 4 per cent. ...	·45 „
Interest, at 4 per cent.	·45 „

Total cost of generation per unit sold, 2·59d.

Producer Gas.

3 lbs. of coke per unit, at 16s. per ton.

Coke	·25 pence per unit
Oil, water and stores	·20 „
Labour in station	·60 „
Repairs	·24 „
Management, rents and rates ...	·37 „
Depreciation, at 4 per cent. ...	·65 „
Interest, at 4 per cent.	·65 „

Total cost of generation per unit sold, 2·96d.

Steam.

10 lbs. of slack per unit, at 8s. per ton.

Slack	·42 pence per unit
Oil, waste and stores	·20 „
Labour in station...	·60 „
Repairs	·24 „
Management, rents and rates ...	·37 „
Depreciation, at 4 per cent. ...	·77 „
Interest, at 4 per cent	·77 „

Total cost of generation per unit sold, 3·37d.

From the above figures will be seen the enormous importance of keeping down at the lowest possible point the capital expended. It may be urged that it is unnecessary to allow 4 per cent. for depreciation, and the same amount for interest, as a local authority can usually obtain twenty-five years for the repayment of its electric lighting loan, and the annual amount to be set aside each year for the repayment of the loan, allowing 3 per cent. for accumulating interest, would only equal 2¾ per cent., and money can be borrowed by a local authority at 3 to 3½ per cent.; but it is much better to keep figures perfectly safe, and the larger the amount provided for depreciation the sounder the undertaking will be. It is also doubtful if a company could borrow under 4 per cent.

It will be noticed that in the Oil and Town Gas stations small plants are suggested for running the load from midnight until the following evening. These plants are so perfectly made that they may be safely left to run without any attention, and will be found to be much more economical and reliable than accumulators.

In most small places where gas companies are in existence, it will probably be possible to obtain gas at a lower price than 2s. per 1,000 cubic feet, and then, when the works had been running for a few years, it might be found more economical to use producer gas.

If steam is adopted, the locomotive form of boiler will save a large amount of capital by dispensing with brick chimneys and flues, and it will be advisable to run non-condensing during the first few years. The figures given show the results in what may be called a middle-sized small place; in larger towns producer gas or steam would compare more favourably, while in small villages town gas or oil would have still further advantages.

It is not necessary to discuss at length the system of supply to be adopted. In most small places a two-wire 200 or 220 volt continuous-current system would be most suitable; but in some cases where long distances had to be covered, alternating currents at 200 volts, with step-up and step-down transformers, would be very convenient and simple.

The main thing in designing a generating station for small places is to try and simplify the working arrangements as much as possible, as it will be impossible to employ highly-paid engineers to take charge of the undertaking.

The next point which the engineer must consider very carefully is the method of distribution. Most small places are scattered over a considerable area, and the length of mains per consumer will be much more than in large towns. Consequently a great effort must be made to reduce the cost. This can readily be done if overhead wiring is adopted, and in a small town of a rural character no argument of any importance can be advanced in opposition, while the arguments for overhead wiring are very strong.

1. It is much more economical.

2. More easy to keep in order.

3. Easy to substitute larger wiring when small wires are overloaded.

4. No disturbance of the pavement is necessary to connect consumers or find a fault.

5. The cost of connecting consumer is very materially reduced.

To show the difference in cost between underground and overhead construction let us proceed with the example already considered, and assume there are 120 consumers connected and three miles of mains, the sectional area being ·1 of a square inch. With overhead wiring it would not be advisable to fix such heavy cables in many streets at first, as it could so easily be replaced by heavier cables later on if it became overloaded.

DISTRIBUTING SYSTEM WITH UNDERGROUND CABLES.

	£
3 miles of ·1 single cables, laid in wooden troughing ...	1,290
20 cable connecting boxes...	80
120 service boxes	240
120 services, including meters, fuses, and fixing ...	540
	£2,150

DISTRIBUTING SYSTEM WITH OVERHEAD CABLES.

	£
3 miles of ·1 conductors, fixed upon wooden poles...	770
120 services, including meters, fuses, and fixing...	480
	£1,250

If we now consider the annual cost of distribution we see clearly the immense advantage of overhead wiring from the financial point of view.

With underground cables the cost per unit will be as follows :—

Labour	·12
Repairs	·16
Management, rents and rates	·16
Depreciation, at 4 per cent.	·69
Interest, at 4 per cent.	·69
	1·82d.

With overhead cables the cost per unit will be :—

Labour	·12
Repairs	·16
Management, rents and rates	·16
Depreciation, at 4 per cent.	·40
Interest, at 4 per cent.	·40
	1·24d.

If we add the cost of generation—2·59d., the total cost of production with the overhead cables becomes 3·83d. This is for the second year's working. As the demand increased the cost of production would decrease, so that we may reasonably expect to see small undertakings working profitably and charging from 4d. to 4½d. per unit.

It will be noticed that the cost of services, meters, etc., is included in the above figures. It is usual to charge a sufficient amount for meter rent to cover the interest and depreciation upon the capital so expended, so that this item might be neglected, which would still further reduce the costs of production, but on the other side of the accounts will usually be found an allowance or discount if the accounts

are promptly paid, and this amount has been considered to balance meter rents.

The staff required to work the gas-driven plant would be :—

One Engineer in charge	at £130
One Assistant	„ £68
One Junior	„ £52

These would during the day fix meters and services and carry out any extensions of the overhead wiring, and the time expended upon such work would be charged to capital.

It is impossible to conclude a paper upon this subject without pointing to the senseless opposition of many local authorities, who obtain a provisional order for the supply of electricity and then spend years debating the expediency of starting the undertaking, or who do nothing until some effort is made to start a company, and then object to the order being granted. It would appear that some effort must be made to make the local authorities realise that they are responsible for the backward condition of electricity supply in small places, and that in the general interests of the country they must either take up the business themselves or allow the supply to be undertaken by local companies.

Mr. W. Emmott said that he was quite at one with Mr. Mountain in his views generally, regarding the supply of electricity to small towns, and as to the causes of such backwardness. At the same time it was a pleasure to be able to state from his own experience that matters were improving in this respect, and he was glad to say that there was a more healthy feeling springing up. The smaller Urban Districts and towns were beginning to realise the fact that they had a valuable property in their provisional orders and also that they could not go on playing the "dog in the manger" for ever. Ratepayers were awakening and the Board of Trade was beginning to let the small Councils know that they would have to move or let some one else move. Mr. Emmott.

He quite concurred in Mr. Mountain's remarks as to the assistance we ought to obtain from the Local Government Board and the Board of Trade. He had tried in three instances in 1900 and 1901 in which they had provisional orders to get, to induce the Board of Trade to let them insert a clause empowering the local authority to lease or sell motors, and to do other things which came within the province of electric supply, but unfortunately they could get no alteration or assistance from the Board. This was so much a provincial matter that the Leeds section of the Institution of Electrical Engineers ought to do something in forming a Committee to take the matter up in order to bring pressure to bear through the local Parliamentary representatives with a view of getting the Board of Trade to give a little more latitude in this direction, and he intended laying a scheme before the Chairman with this end in view.

In the case of a large town like Leeds the expenditure of £2,000 or £3,000 in order to get a special Act of Parliament was as nothing, but for a small place it was such a serious matter that they could not do it,

Mr. Emmott.

and these small places could not fight against what may be called the anti-municipal trading section of the community, which, he thought, carried things somewhat too far.

Regarding the large power schemes, he did not see what good they would be to small places of say 10,000 inhabitants for lighting purposes, unless it happened to be an exceptional place in regard to a day-load. This opinion was confirmed by the report of Mr. Parshall just issued with the Yorkshire Power Company's prospectus, in which he noticed that a plant capacity of 10,000 k.w. worked out at £52 per k.w. for capital expenditure, while the receipts for current sold came out at £7 10s. per annum. Taking the average price to be obtained for current at 2d., this equalised 900 units per annum per k.w. of plant installed. He had made a theoretical load curve on this basis, and it required no great mental effort to see that the small towns and villages were not likely to be of use in making even the modest dividend of 5·83 per cent.

As to destructors his experience told him that where five tons of refuse can be obtained per day it would pay to put down a destructor, and part of the whole cost of this should certainly be borne by the sanitary department, or this department would have to sink capital in ground for a tip, and often pay more in cartage of refuse to a tip than to a destructor. By letting the electricity department bear the cost of destroying the refuse, and returning the clinker to the sanitary department, that department was benefited while the steam generated was doing good to the electricity department. There was now no difficulty in regard to combined destructor and electric stations. They had got now to such a state of efficiency that it was easy to get guarantees of 40 k.w. per ton of refuse with good engines and dynamos. He had obtained more, but he had no difficulty in getting 40 k.w. per ton if the plant was carefully designed and the whole arrangements carried out on proper engineering lines. He preferred where he put down a destructor station to have a storage battery. It was advisable to destroy the refuse without loss of time and then to store up the energy.

Regarding gas-driven stations undoubtedly there was a field open in this direction, especially where the Council owned its own gas works, but his experience was that the author had somewhat underrated his gas consumption, for to run as he proposed twenty hours out of twenty-four with little or no load, his engine would be running very light, while all the time it was taking gas to drive it, and considering that even with vertical gas engines of the most modern type they could only get a guaranteed mechanical efficiency of about 85 to 86½ per cent. (he could not get any more, depending on the amount of load), if the engine were running for twenty hours, there must be a considerable amount of gas simply running the engine, which would increase the cost per unit for the time during which current was supplied. He had, some time since, got out the return for eight months of a gas-engine station as follows:—

The average gas consumed, current being measured at the switchboard, worked out at 64 cb. ft. per unit. The engines were by a

leading maker, chloride storage battery, 3,500 lamps on the mains, but practically no day load. Mr. Emmott.

The gas cost 2s. 9d. per 1000 cb. ft., therefore it worked out at 2·2d. This was a rather large consumption of gas, but the efficiency of the dynamo was not very high, and there was the loss in storage. He had tried another place, and took a 30 B.H.P engine, and that worked out at an average of 35 cb. ft. of gas per unit. Another test of a smaller engine, 16 B.H.P., at the same place, gave 34 cb. ft. per unit. He could not say why the smaller engine should have come out more efficient than the larger one, but he found that the large engine had got an excessively heavy fly-wheel on one side only, and also a large fly-wheel on the dynamo and a very long drive. It was said that fly-wheels did not take any driving, but this proved the contrary.

As to the advisability of putting in a battery where there was a gas plant, a battery was required in order to save running the engine with no load. It paid to have a 30 per cent. loss in the battery, together with interest and sinking fund charges, rather than to keep the engine running night and day. Moreover if the engine were of the "hit and miss" type the battery was almost a necessity.

Gas companies being under no obligation to supply gas for power purposes, but only for lighting, the thermal efficiency varied considerably, and the speaker had found it as low as 400 B.Th.U. per cb. ft.

At Hebden Bridge they were putting down a gas-driven station on lines which he believed were quite new. The Council owned the gas works, having bought out the local gas company, and among the plant was a Glasgow and Humphrey water-gas plant, which cost about £5,000, but with the present comparatively low price of coal and for other reasons this plant was practically idle, and in order to provide work for it, the question of power gas had been carefully considered. The Mond plant was found too expensive for a small place, as other gas plants would do the work cheaply and satisfactorily. In order to settle practically the utility of the Glasgow-Humphrey plant a gas engine had been put down and run at different loads up to 48 B.H.P., the carburetting process of the plant not being used, as the cost of the oil would bring the cost of gas beyond that of gas produced by other water-gas plants in the market and therefore the plant was used purely as a water-gas generator.

The result of experiments extending over some three weeks had resulted in the Council deciding to utilise the plant. The tests were most carefully made, the engine being braked on the fly-wheel in the usual manner and indicated at the same time. The gas was metered into the engine and the thermal efficiency of the gas regularly measured by a Junker's calorimeter and reduced to standard temperature and pressure, the coke was weighed into the producer and the gas passed into a large holder. Briefly, the result was as follows: The gas committee had arranged to sell and deliver the gas to the electricity department at 6d. per 1,000 cb. ft., which left a good profit to the gas committee. Guarantees had been obtained from the engine builders to give one kw.-hr. per 60 cb. ft. of gas, the thermal efficiency of which averaged 244 B.Th.U. per cb. ft. The engines were of the four-

Mr. Emmott.

cylinder type, 250 B.H.P. direct-coupled, and to run at 250 R.P.M. As the gas was somewhat richer in hydrogen than some of the producer gases, the piston as well as the cyclinder had to be water-cooled to prevent heating and pre-ignition.

As to Mr. Mountain's suggestion, he should be a little nervous about leaving a plant to take care of itself all night, and was afraid it would often be awkward if the consumer had no other illuminant to fall back upon.

As to overhead wires. In very small places overhead wires might be put in, but in his experience they were not entirely satisfactory. He had run from August, 1890, to 1893 with overhead wires, in Halifax, at a pressure of 110 volts for the central part of the town and for the outer area at 1,200 volts transformed down to 110. These overhead wires were a continual source of anxiety and the upkeep was more than that in underground work. He would prefer to see how he could reduce other costs, and lay the wires underground. He would not go to the expense of putting down troughing, but would run the risk (if any) of putting down lead-covered armoured cables. The cost of opening out and filling in the ground and making good pavements in country places was not so serious as in a place like Huddersfield. The roads could be opened out and filled in for about 1s. per yard.

He ran the National Electric Supply Company's Preston lighting for about twelve months overground on pitch-pine poles, but was glad when they had to be taken down. The engines were of the semi-portable type, suggested by Mr. Mountain, and were made by Marshalls, of Gainsborough. They were very satisfactory, but the coal bill was high.

Mr. Wilkinson.

Mr. G. Wilkinson said that the supplying of small towns opened up a very large field, the fringe of which had hardly yet been touched. A scheme might be prepared for a small area and presented in the best manner, but the authorities nearly always turned round and asked where a similar one was to be seen; and it was natural that any Town Council should hesitate until they could see something like the one proposed. This he thought largely accounted for difficulties 1 and 4. The principal reason that had delayed lighting was the visionary one that District Councils had as to the grand time that was coming when the Power Companies would be able to give them power practically for nothing.

It was his duty not very long ago to approach the Yorkshire Power Company on behalf of a District Council with regard to terms of supply. They asked for a minimum supply of 25,000 units at 3½d. per unit; from 28,000 to 125,000 at 3¼d. Up to 187,500 at 3d. (It would be a rather large village which would take that.) Up to 250,000 2¾d., and over that 2½d. per unit delivered. To these must be added losses in distribution.

In reply to a question by Mr. Mountain as to what they would do with the supply the speaker said that they (the Power Company) proposed to supply at a given fixed point at this rate, and as a concession the District Council was to take the bulk of the energy and deal with it as they pleased. He found that to this item must be added £8,500 to

£9,000 in putting down mains, house services, meters, buildings, etc. An engineer and manager would have to be engaged, and all the risk of bad debts and the like would have to be taken, and in fact, except for the stoking of boilers, the entire business of supply would have to be undertaken. In the case of villages the whole of the capital outlay must be most carefully spent; there was no margin to work upon, as was the case in a large area where the lighting density was fairly heavy. Mr. Wilkinson.

He did not think that the future lay with destructors, unless there was a strong reason from a sanitary point of view, as the initial outlay was very large indeed, and the advantages did not warrant it. He thought the refuse should be put on the land rather than burnt, as there was in many of these areas plenty of tipping ground.

It was difficult to say what form the combustion engine would eventually take, but he did not think steam had any chance. He thought there was something to say in favour of oil and town-gas rather than producer-gas and steam. In the paper, 10 lbs. of slack per unit at 8s. a ton was mentioned, but he did not think that there were many places where it could be obtained at that price, as there are many villages where cartage would cost you 2s. 6d. per ton. Regarding town-gas figures, the price was put down at 2s. per 1,000 cubic feet. In Harrogate the least it could be obtained at was 3s. 2d., less 10 per cent.; in Otley it was 3s. 4d.; Wells was 5s. 3d. and Tadcaster 5s. 3d.; and he, therefore, thought that this figure should be increased very considerably. Again with regard to combustion engines he said that he knew one of the big supply companies was just concluding a contract for a 1,000-kilowatt internal combustion engine rather than increase their boiler and steam plant.

As to oil-engines. Oil was given at 0·5d. per unit, but he thought it could be done for very much less. He should be inclined to put it down at 0·23 to 0·25d. Another point with regard to the 4 H.P. plant to be used instead of accumulators. His opinion was that it would not be safe to allow it to take care of itself entirely. Up to a few months ago he produced his own electricity at home by a 3½ kilowatt dynamo driven by a Paris-Singer gas engine. Accumulators were not used, and the cost of running did not exceed the cost of lighting by gas. Accumulators need not be very expensive, and would be a safer arrangement, the station could be shut down entirely for daylight hours, and they would give an economical load while such plant was running, and he would very much prefer to use them.

Mr. Mountain said "the estimated lamps connected during the first two years are 3,000 of 8 c.p. . . . and the first instalment of plant would therefore require to be equal to about 60 kilowatts." It did not appear from this that any spare plant was provided, and he would be glad of further information because it was always understood that a certain amount of stand-by was an absolute necessity, and he therefore thought that the capital outlay would have to be increased for this stand-by plant.

He quite agreed with Mr. Mountain as to the future of overhead rather than underground distribution for thinly populated areas, as it was very much easier to look after the distribution of overhead than

Mr. Wilkinson.

underground cables, and there were no expensive joint boxes as in an underground system.

Mr. Harris.

Mr. HARRIS said that towns' refuse was now being largely employed in the production of electricity at a cheaper rate than any other method in existence where fuel was to be used, and the consulting engineers in general were now recognising this fact. Professor Kennedy, for instance, had at the present time 4 or 5 stations where he was recommending a refuse destructor because of its cheapness. From a sanitary point of view the refuse should always be destroyed, and corporations and councils had come to the conclusion that a destructor was necessary and that they might just as well have a return for the cost of the outlay in the production of electricity. This was an important factor in determining the electric light stations being put down at Cleckheaton and Shipley. He was of opinion that it would pay all towns, and small towns in particular, to take up the subject and bear the whole cost of putting down the refuse destructors in connection with electric light stations.

He gave a comparison between the cost of generation by coal and by refuse. Taking an average cost of fuel and wages, and allowing in each case only one man for the boilers, he showed that the difference was very great indeed. Taking a yearly output of 87,000 units the average price per unit (taken from the *Electrical Times*) was 1·353d. With a refuse destructor, including interest, sinking fund and repairs, it was 0·376d. Again, with a coal plant, between 87,000 and 131,000 units per annum, the cost was 1·053d., while with a refuse destructor plant it was 0·391d.

The engine-room charges and interest on the electric light station were left out. Taking again a larger plant of 131,000 to 175,000 units, the cost for coal, firing, and one man was 0·939d. as against a destructor station 0·295d., and coming to a still larger one of 350,000 units coal, firing, and one man 0·916d. as against refuse destructor 0·264d. It was certain that only the largest stations in the country were producing electricity with a fuel cost of anything like 0·26d. The figures would allow for ample margin for interest and sinking fund charges, and the working results in different places confirmed these figures.

At Darwen for the last financial year the refuse destructor effected a saving equal to £1,050 in coal, although they were working non-condensing, and if they had had an economiser the saving would have been very much greater. It was quite the usual thing to get 40 units per ton of refuse, and in some cases over 60 units, and he expected to hear of still more. He thought that it would pay station engineers generally to push the subject more than they are doing, and advocate the use of town refuse instead of coal.

Mr. McLachlan.

Mr. MCLACHLAN said that there seemed to be some misunderstanding with regard to the cost of gas in small villages. It was produced in York for 1s. 10d. per 1,000 cb. ft., whereas it was quoted as at 3s. 2d. in Harrogate and 5s. 3d. in Tadcaster. If an agreement were made with the gas company it was probable that it could be obtained at from 8d. to 1s., which reduces Mr. Mountain's figures by 50 per cent. With regard to producer-gas, Mr. Mountain was on the right side, as

guarantees could be obtained to produce a unit for 2 lbs. of coke, as against the 3 lbs. given in the paper; and, again, coke could be obtained at from 8s. to 10s. per ton from many gas companies, as against the 16s. given in the paper, and this still further reduced the cost. He thought that the repairs might have been brought down a little more. If all these things were reckoned together it would be seen that electricity could be produced for about 2d. per unit, which was a saving of nearly one-third. The figures given by Mr. Emmott, viz., 64 cubic feet per Board of Trade unit, were rather peculiar, because any good type of gas engine could now be reckoned to consume something less than half of that. Passing on to the question of power he said that nobody seemed to have thought of the fact that electricity could be used for power in small villages, although not to any large extent. Mr. McLachlan.

Mr. M. B. FIELD said that he could not agree with Mr. Mountain that the total cost per unit would come out at 3·83d., and that there would be a good profit at 4½d. with a plant of the size contemplated by him. The question as to whether it was going to pay to supply small villages from a large power station depended on many things, amongst others, on the size of the village, and the amount of power required; also upon whether power could be conveniently tapped off from a line arranged to supply, say, a very much larger village somewhere else. The question was largely determined by the matter of overhead lines or underground cables, and he did not see why there should be any uneasiness whatever with regard to the former. Mr. Field.

They were universally adopted in the United States and Canada and on the Continent, and he thought that when the Board of Trade had sufficiently advanced to allow them that there would be a far better chance of supplying small towns and villages from the large power stations at a comparatively cheap rate.

In regard to the objection of Mr. Mountain to the large power schemes on the ground that buildings would be necessary and machinery would have to be erected, attendance provided, etc., he could only say that in America lines were run for many miles and absolutely no attendants were provided for at the far end for carrying out the transformation or distribution of the energy.

Mr. E. A. PARIS said that as one of the oldest missionaries he had passed through the various phases of the several controversies — continuous-current *versus* alternating-current, accumulators *versus* running plant, and large central stations against small isolated plant—and he was certain that the small isolated plant with a highly efficient prime mover would win the day. Mr. Paris.

He thought that the oil-engine had a very great future before it, more especially for the kind of lighting treated of by Mr. Mountain. He agreed with the author as to the senseless opposition of many local authorities, who obtained a provisional order and then did nothing until some effort was made to start a company.

Mr. S. D. SCHOFIELD said that he considered Mr. Mountain had taken some very low costs, as there were many stations even in the coalfields where the coal cost exceeds 0·42d. per unit. If stations with from 500 to 800 kilowatts installed could not get below 0·6, and in some Mr. Schofield.

Mr. Schofield.

cases 0·8 or 0·9, how could a country village be expected to get to 0·42 or anything below 0·5d.? In some cases it would be more economical for a private company to start a supply in a village without obtaining a provisional order, as they would be in a better position owing to there being no restrictions against overhead conductors. The success or otherwise of a small station, quite as much as the success of a large one, depended upon the *esprit de corps* of the staff. He thought that the engineer that would make a small place successful would be one that was always out canvassing and who would act as consulting engineer for the wiring of installations and would advise upon the installing of motors in order to help to get a motor load.

Mr. Wallace.

Mr. G. S. WALLACE said that before wires were erected permission would be necessary to carry them over property, although, of course, if the District Council were doing the work the difficulties would not be so great on the main roads, but they would still have some difficulty in going over private property, and with a private company this would be more noticeable and would increase their annual charges very considerably. Again, he thought that there would be a great fear of the wires, as the demand increased, becoming very unsightly, and that in consequence objections would be raised, which would in many places lead to their being removed. He was surprised to see that the repairs in each case were taken at 0·16d. per unit, as he was sure that, if the underground system were properly laid, the repairs should not be so high as for the overhead system. He noticed that the cost for depreciation for underground cables was 0·69d., whereas for the overhead it was 0·4d. Seeing that poles had to be taken down and possibly erected elsewhere and that they required renewing at certain intervals, he thought that the depreciation would be greater with overhead cables. If there were at all sufficient margin to allow for underground cables in the initial arrangements of the plant he should certainly recommend them rather than aerial wires, because when a good supply was obtained the aerial cables would have to be replaced by underground conductors.

Mr. Broadbent.

Mr. BROADBENT said that he had a small private plant in which the cost of production in gas came out at 0·75 per unit, but the accumulator depreciation brought it up considerably. He supplied energy to friends at 6d. per unit and charged them 15 per cent. per annum on the cost of mains. He found that it was best to run his gas plant at the full output and use accumulators.

Mr. Brook.

Mr. BROOK said he could speak with actual experience as to the reasonable figures given by Mr. Mountain. He gave some particulars of a gas-driven plant put down by him at Brighouse. Over 4,000 8 c.p. lamps were connected to the mains and 84 brake h.p. was installed and a storage battery was also used. The revenue from the sale of current was about £550 a year, which works out at about 1s. 9d. per lamp. The units sold were 23,000, which could be increased by applying a little encouragement. Current was charged for at the rate per unit of 6d. for lighting and 5d. for power. Owing to the fact that insufficient plant was installed to take the maximum load the battery had to take a large share of the supply, and the cost per unit supplied was fairly high. Gas was charged at 2s. 9d. per 1,000 cb. ft. from

the town mains. He thought that the power companies would find a great difficulty in supplying most of the small towns and villages. He thought that the item for repairs in the four cases given was rather high and should be brought down to one-half. With regard to overhead wires, during the whole six years that he had charge of the Brighouse plant they required no supervision whatever, and he never had any breakdown owing to the failure on their account. Mr. Brook.

Mr. A. L. C. FELL drew attention to a rather misleading point on page 1018, in which it was stated that public companies would supply at 2½d. per unit, whereas it could be generated (it was said) for ¾d. or 1d. On page 1021 it was shown that at the very best it could only be produced for 2·9d., and he did not see how these figures agreed with one another. Again Mr. Mountain stated that in a case of a tramway undertaking the revenue commenced at once, whereas the revenue from an electric supply undertaking could only grow gradually, but he did not think that this was quite correct, as, for instance, in Sheffield the revenue had gone up considerably with the same number of cars running. Mr. Fell.

With regard to the question of steam generation he thought ten pounds of slack per unit a great deal too high, as five or six pounds per unit was quite sufficient; and, again, slack could be obtained for something like 6s. per ton, as against the 8s. given in the paper.

He did not see any reason why the Board of Trade should not consent in the case of a small village to do away with the present regulation to the effect that the plant should have to run all night, as he thought it could be shut down at eleven or twelve o'clock, and if this could be done there would be a chance of running the plant at a considerably lower cost. He thought that the local authorities did not take up the question of supply because of the misleading statements which were made about the large power companies, and they did not trouble to inquire as to whether they could not supply themselves more cheaply.

Mr. BAKER (*communicated*) thought that the author's proposal to work a small plant all night without attention was a bold stroke, but at the same time it was warranted by experience. He himself had frequently, in a small private plant, left the engine working all night charging accumulators, and he did not remember that on any single occasion was there any trouble. Mr. Baker.

He differed materially from Mr. Mountain concerning the value of electric power supply companies, as electricity supply became a simple matter for a local authority when the generating works were dispensed with and the problem was simply that of purchasing in bulk and retailing at a profit.

In the paper attention was directed to the employment of motor-generators, but a large volume of the business of the power supply companies would be done through stationary transformers supplying alternating current. He thought there would be a reduction in the cost of the distributing mains owing to the central position in which such a transforming chamber could be located. Again it might frequently be practicable to use one generating station for several small towns close together.

Mr. Baker. He thought the author was right in eschewing condensers in connection with small steam generating plant, unless there happened to be an available stream of water sufficient to work an ejector condenser. The use of a destructor would very materially increase the capital cost in a small system, and a reasonably large accumulator must be added. The most suitable towns for the combination of refuse-destructors and electrical works were those having from 10,000 to 30,000 inhabitants, the limiting number being a sufficient population to provide refuse, and on the other hand a population whose demands are within the range of an accumulator, of which the prime cost was a determining factor. He thought it would be difficult to find an example of 30,000 units per annum being generated at a total cost of 2·59d. per unit, though the figure might be obtained.

Some slight advantage was obtained by pushing the supply voltage as high as possible, particularly when accumulators were not employed, and he thought that the 200 to 220 volts should be made 230 or 240 volts at the consumers' terminals.

Mr. Cruise. Mr. E. G. CRUISE (*communicated*) wrote that the question was of undoubted importance at the present time to electrical engineers, companies, local authorities, and to the industry generally, as the list of large and important towns in the United Kingdom where a supply of electricity had not been already inaugurated or arranged for was fast becoming exhausted. It was, however, somewhat alarming for the financial outlook of the electric power companies to read the confirmed opinion of the author and many of the engineers joining in the discussion that these companies would have no field whatever for their work of bulk supply amongst the small towns and villages. When these power schemes were before Parliament for the first time in 1900, the evidence submitted to the special committee which first sat to deal with the schemes was largely directed to show that only by the sanction of these power companies could the small towns ever hope to obtain a supply of electricity at a rate profitable to consumers. Parliament was impressed with this argument and the evidence which supported it; it destroyed the opposition evidence, and there was little doubt but that it was in large measure responsible for the passing of the Pioneer Act, the County of Durham Power Scheme. The precedent once set, the subsequent Acts were more easily obtained, and the evidence referred to was repeatedly quoted in the progress through both Houses of the multitude of Power Acts which had now become law. The special committee above mentioned consisted of eight instead of the usual four members, and had been chosen to include some of the best known business men and financial experts of the day, so that due weight must be given to their judgment regarding the schemes. For the purely engineering evidence they were, of course, necessarily in the hands of the electrical engineers who gave evidence. The underlying principles, however, of the Power Acts were in such large measure principles of financial economics, that it may be taken that their passing by Parliament was tantamount to conviction as to their benefit to electricity consumers in the lesser towns and in outlying villages.

He had no doubt that the evidence before the committee was also well known to Mr. Mountain, but he had perhaps lost sight of the fact that the present rates offered by the power companies were in no sense indicative of the ultimate rates which they would be able to offer. Obviously so long as their load-factor was not vastly more favourable than that of the local supply station, they must commence by rates which would secure them against working at a loss. Even with these initial rates, however, there would seem little room for doubt that they would be widely accepted by the authorities proposing to distribute in the small towns and villages. One point, however, to which Mr. Mountain very rightly referred was the absolute necessity of obtaining sanction from the Board of Trade to having overhead transmission lines, and if this applied to the local distribution, assuredly it applied with double force to the trunk lines of the power companies. This would seem a point to which the power companies had not, so far, given sufficient attention. The explanation might lie in the fact that cable companies were largely interested in the power companies. Agitation on the subject had been developing lately, and even in 1900 a special committee of the London Chamber of Commerce had been appointed to approach the Board of Trade on this subject, and a full report dealing with the question of overhead wires and other questions regarding the economic aspects of the carrying out of the Power Acts, was issued by the Committee. So far no general concessions had been made, but the Board of Trade was undoubtedly now more disposed to deal favourably with the question of overhead transmission, a system in universal use except in the United Kingdom. He ventured to think that the wholesale laying of underground power cables in these schemes at costs of and above £1,000 per mile per 1,000 k.w. cable would wholly defeat the ends and destroy the financial success of the power companies. Mr. Cruise.

But whether the power companies prospered or not, or whether they offered rates far below those obtainable from isolated stations, there was no doubt that there would always remain small and truculent towns where the local authority, or even perhaps a company, would insist on putting down their own generating plant, and it would be in the consideration of such cases that Mr. Mountain's paper would have immediate application. Further than this, there would be many such towns where power companies would have no trunk mains for years yet, if ever, and such places would require a pioneer or permanent isolated plant.

Regarding, therefore, the actual questions arising out of the paper, he ventured to suggest a few points. From personal experience of an Inquiry held recently by the Local Government Board for a loan of £6,000 for electricity works in a very small town of 4,000 inhabitants, he was able to say that in such cases the Local Government Board would probably not consent to a sinking fund for repayment of the loan. In the particular case in question they absolutely refused to sanction any other scheme of repayment of the loan than the yearly repayment in cash of the total sum of the loan divided by the number of years it was to run. Thus, the best terms obtainable being a period

Mr. Cruise. of twenty-five years, it was evident that an initial annual charge of 4 per cent. on the capital of the undertaking must be allowed for as against the figure of $2\frac{5}{8}$ per cent. submitted by Mr. Mountain. Taking interest at $3\frac{1}{4}$ per cent., we arrive at a total of $7\frac{1}{4}$ per cent., thus leaving practically nothing for depreciation in Mr. Mountain's tables, and the Local Government Board are very exacting in the case of small schemes for some prospect of such provision. To meet the case, therefore, under the circumstances the price must be raised above the figures given in the tables.

Regarding more especially the producer-gas figures, it was very doubtful whether for such small plants as those in question manufacturers would give any satisfactory guarantee as to the quality and continuity of the gas generated if coke alone were used. The figure of 3 lbs. of coke per unit sold seemed altogether too low, seeing that in the case of Walthamstow a very successful and typical producer-gas station, where the sets were 75 k.w. output each, and best pea-nut Anthracite coal was used, that the figure per unit sold was about 3·2 lbs. of fuel. In the case of really small towns and the proposal to use town gas where available, it would seem that the figure of 2s. per 1,000 c. ft. is too favourable. This in many cases would undoubtedly be below the cost price of making the gas. In the town above referred to the price was about 5s. for any purpose, and this would appear to be a not uncommon figure in very small towns. In such cases town gas was out of the question. Regarding the overhead distribution wires, the Board of Trade would only so far give a provisional sanction for five years, and this not in all cases, and apparently if wooden poles were proposed, the Local Government Board might shorten the period of the loan. The proposal to have an all-night running of the plant with a small set was a novel and interesting one, but it appeared to be very desirable, especially in a small station, to have a small battery at least, to give the necessary light in case of a breakdown. Such accidents would happen to small plants, and the difficulty was largely increased if no good source of light were available for immediate inspection of the various parts of the plant.

Mr. Mountain. Mr. A. B. MOUNTAIN said that he would reply to the points in the paper as they occurred, and not to the individual speakers. Taking first the considerations that appealed to the influential people, the difficulty was that one must somehow persuade the people who live in the district that one can give them a supply at such a cheap rate that they would adopt it, and that the undertaking would be financially successful.

In large cities like Leeds, with all its conveniences, he did not think they appreciated the backwardness of the small places. There were thousands of places in England where there were no street lamps, and no effort whatever was made to light the houses, and in those places small plant could be put down and run at an exceedingly low rate. In a country place a small gas engine could be put down and allowed to run alone all night to supply, say, 50 lights, which was all that would be required. Engine lubrication was now so perfect that there was not

the slightest difficulty in letting them run by themselves for 12 hours. Mr. Field put the case for the power companies, and, assuming that the power companies could supply the works here at a cheaper rate than the works could provide power themselves, Mr. Field was no doubt right, but an examination of figures showed that the cost of producing energy in mills was only something like 0·2d. to 0·3d. per unit. It seemed impossible for any power company to persuade the owner of that works to scrap his steam plant, and put in motors, and take the supply from them, even if they could come to that price, and Mr. Field would agree that it must be many years before they could supply at a price anything like that. Further with regard to power companies, he said that the distributing authority must have some central point or have sub-stations for distributing, and to which the power companies would bring their supply, thus leaving the District Council with the whole of the cost of the distributing services, and mains and other items, including management. He did not think that there was the slightest possibility of the power companies ever helping in any way in the supply for small places. Mr. Mountain.

With regard to the criticism of the figures, he thought that he had not under-rated the amount which would be required to run the works; the figures were taken from certain engineers who had gas-plants under their control. It was quite possible that the average figure would be slightly higher than 25 cb. ft. per unit. If the figure was altered from 25 to 30 cb. ft. per unit and the price of gas reduced 6d. he would be on the right side, and eighteenpence per thousand was quite high enough.

Mr. Emmott was very severe on the question of overhead wires, but if he were given the opportunity of pushing electricity he (the speaker) thought that he would agree with him that ½d. or 1d. per unit in the cost made all the difference between a scheme succeeding and failing, as the question of cost in a small place was far more serious than in a large place. In a small place the working-class had to be supplied, and therefore the very cheapest system must be used, and he was convinced that if we went in more for overhead wiring we should find the simplest way of getting over the difficulties. He found that the repairs themselves to underground mains were not expensive, but when the cost of taking up the roads and also of interference with the traffic was considered, the item was a very serious one.

In the case of overhead wires put up firmly on poles, repairs could be undertaken by anybody without specially skilled knowledge, and they were easily accessible in case of a fault occurring, whereas in the case of underground mains, there was trouble with the District Council if it was a private company, and friction between the various departments if it was a Corporation.

If destructors were adopted, the first thing to do was to encourage in every possible way the adoption of electricity for motive power purposes.

Mr. Emmott mentioned small batteries, but if there was one thing an engineer must fight against, it was the employment of small batteries, and with batteries there must be some one who really understands

Mr Mountain.

what he is doing, as there are more batteries destroyed from want of knowledge than probably anything else, and he was therefore suggesting the employment of small engines to replace batteries, and he felt certain it would reduce the costs considerably.

Mr. Fell has drawn attention to the statement that the cost of production would be ½d. or 1d. as against 2½d. if purchased from a power company, and then points out that the cost of production as shown in my paper is 2·9d. This figure includes management, depreciation and financial charges, all of which will require adding to the 2½d. paid for the energy.

Mr. Cruise has stated the case for the power companies very forcibly, but beyond obtaining powers these companies appear to have made very little progress, although they have effectually stopped the introduction of electricity into the small towns and villages which are now reconsidering the matter, and are likely to do so for many years, thus blocking progress.

It does not matter to a local authority whether the capital is repaid by annual instalments or by means of a sinking fund, the total amount to be provided annually is practically the same.

CALCUTTA LOCAL SECTION.

ON THE PRESERVATION AND PACKING OF PLANT FOR AND IN BENGAL.

By PAUL BRÜHL, Member.

(*Abstract of a Paper read at Meeting of Section, March* 27, 1903.)

After an experience of over twenty years in the "care of plant in hot and moist climates," the author refers to the nature of the adverse climatic influences which have to be combated by those in charge of laboratories or central stations, as being mechanical, physical, chemical, and biological.

In the "mechanical" he includes the subject of packing and care in transportation. He regards some conditions in respect to handling of cases containing scientific instruments as unalterable. As regards design he says:—

"Ample and efficient provision should always be made for securing the coils of suspended-coil galvanometers, the magnetic systems of Kelvin and Helmholtz galvanometers, and other loose or oscillating parts of instruments. There is absolutely no sense in the manufacturers fitting on the suspension, and not taking precautions to prevent the suspensions getting broken, before the instruments reach their destination. An ideal which designers ought to keep steadily before their mind's eye is one which Clark Fisher refers to in his book on the potentiometer: an instrument should be so designed that, provided it is properly packed, it should be possible "to throw it across the room with impunity or even to send it by rail in the United States." Portability and security during transit is a condition which most instruments sent out to this country ought to satisfy.

"In machines, sections which give rise to injurious stresses after casting, or such as create lines of weakness along which concussion is likely or certain to produce fracture should be carefully avoided, and pins or bolts or screws which hold parts in position should be designed of a sufficient cross-section to prevent shearing taking place. Some time ago I received an electric motor with the insulation of the wires on one of the end faces of the armature scraped off and the wires partly cut into by some part of the frame. The cause of the mischief lay in a pin which had the function of keeping one of the shaft bearings in position having been sheared right through, probably in consequence of the case containing the motor having been dropped from a railway waggon or into a ship's hold; and a trifling difference in the design of the bearing would have prevented the accident. It would be a good thing if every designer of instruments and machines manufactured for export made himself intimately acquainted with the special conditions

of transport. Personally I believe that, with proper design and proper packing, accidents to instruments need hardly ever occur except in the case of a railway collision."

On the subject of packing—which is an engineering one, and of moment as affecting successful exportation—he says:—

"Most of the larger firms of manufacturers of physical and chemical apparatus have evolved, on the basis of their own and other people's sad experiences, methods of packing which in the majority of cases prove fairly efficient. Of late years I have only rarely received articles in a broken condition; but then I make it a point to deal only with first-class firms. Very effective is a description of wood shavings, consisting of very thin, very long, and very narrow strips which seem to be specially manufactured for the purposes of the packer.

"It is self-evident that parts should never be lying loose in their box. One of the worse sins of commission on the part of a packer is to pack very heavy and bulky articles in the same case with delicate parts; and yet that is done again and again, as if the packer considered the heavy parts to be specially designed to triturate the delicate parts into a fine powder. All heavier parts should be tightly fastened down by screwed-on battens; and if it is found unavoidable to pack smaller articles in the same case with larger and heavier ones, they should be packed in separate small boxes. All this seems simple and self-evident; but unfortunately sufficient attention is not always paid to these details, and it is astonishing what thoughtless blunders are sometimes perpetrated by the packer."

On the subject of temperature he says:—

"It does not appear to me that the higher temperatures of the tropics and sub-tropics, taken by themselves, play a very important part in connection with our subject. It is doubtful whether any dynamo has ever been injured by being run under full load, although the starting temperature of armature and field-coils has been say 100 or even 110 degrees Fahrenheit, and therefore 20 or 30 degrees higher than the initial temperature would be in England. There are only a few instances known to me of the higher Indian temperatures causing temporary or permanent trouble. One case occurred with one of Lord Kelvin's current balances, in which, during the first hot weather the coils commenced to sweat out some of their paraffin, causing the moveable coils to stick. A small quantity of the more fusible paraffin having oozed out, the remainder having a higher point of fusion remained behind in the solid state, and the balance has been in first-class working order ever since. But it is advisable for manufacturers of apparatus in which paraffin is used for insulating certain parts, to use only paraffin of high melting points in apparatus meant to be used in tropical countries.

"It is possible that the higher temperatures of the tropics have something to do with the dust which may happen to lie for some time on varnished parts of apparatus becoming ingrained in the coat of varnish and spoiling its appearance for good. The only remedy in this case is frequent dusting and keeping the apparatus under cover when not in use."

The effect of high temperatures on chemical agents is discussed as follows :—

" It is different with higher temperatures acting in conjunction with chemical agents ; in this case the influence of temperature ceases to be negligibly small. It is well known that the time-rates at which chemical actions proceed are not only generally speaking functions of the temperatures at which they happen to take place, but they are often rapidly increasing functions of the temperatures and are therefore frequently represented by curves which at first are nearly horizontal, but beyond a certain point curve rapidly upwards. Unfortunately hardly any precise data are available on the relation between temperatures and the time-rates at which such chemical actions take place as the rusting of iron, the formation of verdigris, the action of nitre on various substances interesting to the electrical engineer, the chemical changes which lubricating oil and allied substances undergo in contact with the atmosphere, the action of carbonic acid on various silicates, the action of atmospheric ozone."

The rapid rusting effects in the rainy season are not much prevented by the process of "blueing." For instruments the author has used Vacuum Company's spindle oil laid by means of a brush as a protecting covering. The use of this on the steel parts of exported instruments, the oil being first carefully tested for the presence of acid, he strongly recommends. He recommends that all swinging parts of fine balances and accurate sets of brass weights should be platinised. He objects to gilding ; he prefers phosphor bronze to steel where suitable, and in balances, used in electrolytic work, knife-edges should be of agate.

" Aluminium, provided it is pure, appears to stand the tropical climate tolerably well ; some aluminium, however, becomes quickly converted into hydroxide, and on the whole I do not advise the use of aluminium for parts of instruments ; of course where special lightness is required, the use of aluminium may be unavoidable. There is little trouble with German silver and platinoid. Stretched Iridium-silver wire, as sometimes used in meter bridges, invariably snaps. Bare manganin is not quite climate-proof and requires careful watching. A peculiar change takes place in the suspension strips of the D'Arsonval galvanometers of some makers. After a short time one finds the resistance of the galvanometer to increase rapidly, until it nearly reaches infinity. On examination one finds the strip converted into an exceedingly fragile thread of oxidation products."

Another marked source of trouble are galvanometer mirrors. He says, " I have repeatedly received galvanometers with the silvering of their mirrors either cracked all over and portions of it flaked off or rendered useless by tarnishing. As the best temperatures for silvering such mirrors lie about 20° centigrade, the temperatures ruling in India are usually too high for an attempt to re-silver one's mirrors one's self to prove an unqualified success.

"One of the most powerful corroding agents employed by nature is carbonic acid. We are accustomed to look at carbonic acid as a weak acid ; at least, that is what elementary books on chemistry tell us. Of course, it is weaker than various other acids ; but in many instances it

is weak only because it is volatile—volatility is not usually compatible with strength—or, it is weak because in an aqueous solution prepared under atmospheric pressure it is exceedingly dilute. But when the acid is more concentrated under the action of high pressures, the effect is markedly different. Now capillary action has a similar effect on concentration as a large increase of superincumbent pressure; and the carbonic acid present in the film of moisture which covers all articles during the rainy season, or in the film separating two surfaces in apparent contact, carbonic acid is in a much more concentrated state than corresponds to the atmospheric pressure. Such carbonic acid is capable of displacing the silicic acid of natural and artificial silicates. Here it is where the mischief comes in. Hence the crusts of sodium and potassium carbonates found plentifully in nallahs of Chota Nagpur and Behar during the dry seasons; hence the dimming of surfaces of glass slides in contact with each other; hence the film which ruins lenses kept in confined situations.

"A chemical change of considerable importance to people having to do electrical testing is the oxidation of the sulphur in ebonite with the consequent formation of sulphuric acid. This change proceeds with considerable rapidity especially during the rainy season. Apparatus which are constantly in use and which therefore are frequently wiped down suffer comparatively little. If, however, the insulation of ebonite parts should be found to have broken down, it is best to moisten them with some dilute caustic potash solution, wash them with plenty of hot distilled water and rub them dry with a clean cloth. Having mentioned ebonite, I am reminded of india-rubber tubing and rubber stoppers. It is astonishing how rapidly they deteriorate in this country The best way of keeping rubber stoppers is to put them into a wide stoppered glass jar at the bottom of which is placed an inverted perforated dish to serve as a support for the stoppers after pouring some oil of turpentine on the bottom of the jar. Stoppers which have acquired a hard cracked surface can be softened by proceeding similarly, only using chloroform instead of turpentine. A good way of preserving rubber tubing is to give it a coating of glycerine. Guttapercha bottles, such as are used for storing hydrofluoric acid, are best protected by covering them all over with paper gummed on.

"I shall not take up your time by dealing in detail with the omnipresent microbe; with the nitre-producing microbe which covers our walls and instrument-pillars with destructive inflorescences. Neither shall I occupy myself with the fever-amœba which causes more havoc and financial loss than many a more quickly acting bacterium; its effect on instruments and machines is only indirect, although sometimes patent enough. More direct is the action of mould. I have often observed beautiful specimens of Mucor growing on ivory parts of apparatus, for instance on ivory pins and eyelets used for insulation. It is chiefly new apparatus which are thus affected, just as it is the new binding of books which suffers most acutely from the attacks of mould. But as only certain constituents of the ivory or the binding of books supply foodstuffs to the growing mould, the latter disappears as soon as those nourishing materials are exhausted. Free circulation of air and plenty

of light are probably the most powerful preventatives of mould-growth."

Having had to refer to dust and dirt, he adds, "I do not think that people out here are always as careful as they might be in protecting their machinery from the deteriorating influence of grit and dust. One sometimes notices even in Europe-bred Europeans a tendency to fall in with the views and habits of the natives. Of course, as regards dust it matters little where a carpenter's bench or a blacksmith's forge is placed; an open shed with a dust-generating mud floor is about as good as anything for ordinary work. But it does make a difference whether first-class machinery, especially dynamo-electric machinery, but also finer lathes and milling machines, are plumped down on a gritty mud-floor or in a cobwebby, dark, damp corner, or whether the machines are placed in a well-lighted machine room provided with a proper brick-on-edge or patent stone floor. It is true a 'pakka' floor costs money; but the ruining of good machinery by grit is not exactly a cheap operation either. There is another superstition alive in the minds of some people, and that is that a dark corner is necessarily a cool corner. This is by no means the case; 85° Fahrenheit in a dark damp room is often less bearable than 95° Fahrenheit in a well-aired, well-lighted room. It is quite true that the Indian coolie is accustomed to dirty surroundings, and although hardly thriving on dust and dirt, the coolie feels quite happy in it. But even he is not accustomed to a life in dark confined rooms. A great part of the Indian's life is really spent in the open air and in sunlight, and he will do his work all the better and the more cheerfully if you give him plenty of air and light in your workshops. Probably the best position in Bengal for an engine and machine room is to have its length in a north-south direction. It should have large venetianed doors in the south and north walls, plain walls on the east and west sides, and in these walls a row of large round or square windows higher up near the ceilings. This arrangement provides a good through-draught and plenty of light."

Mr. Williams.

Mr. C. T. WILLIAMS observed that the paraffin wax used in the manufacture of instruments at home appears to be softer than that imported into India for use in the country. This is specially prepared to resist high temperatures. For preventing rust this speaker found that Rangoon oil (the imported, not the local article) was excellent, and that a satisfactory way of storing bright steel parts of instruments in damp climates was to wrap them in paper soaked in Rangoon oil. The Indian Telegraph Department had not hitherto manufactured resistance coils with manganin wire, but this was about to be tried. He was interested in learning that this metal was, in a slight degree, liable to rust, but as the wire would be double silk covered and soaked in paraffin, there would be no reason to apprehend that it would be in any way injured. This speaker drew attention to the very bad work put inside induction coils by some makers at home. It was no uncommon thing to find a coil fail owing to soldered joints being corroded through, this being due to the fact that resin had not been used for a flux. The connection to the condenser was also very faulty. This

Mr. Williams. sometimes consisted of a piece of wire pressing on the tinfoil, and kept in place by a piece of board. The board warped and the connection failed.

Mr. Eustace. Mr. S. EUSTACE said that the conditions prevailing in a hot moist climate were such that it appeared almost impossible to make the mind of an European manufacturer, dwelling in cooler climes, understand. He well remembered at one time writing to a manufacturer and giving him some ideas that would be useful to him in designing machinery for use in India. Instead of gratefully tendering his thanks, he quietly said that as he had been designing machines from the time he (the speaker) was still in petticoats, or a suggestion to that effect, the speaker could not teach him anything. He did not suppose that it was always possible so to design a sensitive instrument, and despatch it, however carefully packed in its working state, that it could be sent by rail in the United States. Manufacturers, however, seemed to think differently, and instead of taking a delicate instrument as much as possible to pieces, and packing the pieces separately, they seemed to consider it sufficient to stuff the moving parts up with silver paper and pack the instruments in straw; and in the latter propensity some seemed to be incorrigible. He admitted, however, that in one direction it was very difficult to preserve instruments properly on the voyage out. The consumers' meters sent out for the Calcutta Electric Supply Corporation, although excellently packed in hermetically sealed cases, as often as not arrived with pinions and gear wheels covered with rust. He would suggest that in a case like this, where the rust must be due to sweating inside the case, that all the cases should be well dried with unslaked lime before receiving their contents, and being sealed up. In the other direction, however, that of mechanical injury due to bad packing, lay one of the chief causes of complaint. The probabilities were that the actual man who did the packing had just about the same amount of conscience as a coolie.

He did not remember any case of a dynamo being burnt out from heat, pure and simple, without some other cause at the back of it. The springs on some of the meters recently imported had been gilded, and this he found fairly satisfactory, though he had had much trouble with ordinary springs previously. He had had cases where a resistance of manganin steel, after withstanding heat for a certain length of time, had disintegrated so that it crumbled in the hand.

There was no question as to what was the fundamental difficulty in preserving instruments and machinery in Calcutta—it was the climate, which had often the same effect on men. Temperature was often a great trouble, and during the hot weather he had known the temperature on the station switchboard to be as high as 112° Fahrenheit, and this with an atmospheric humidity of over 90.

As far as dynamo machinery was concerned, it was advisable to have all the windings well baked before being put into use. He had done this lately with the fan armatures, and the result had been very beneficial.

Mr. Simpson. Mr. M. G. SIMPSON would like to add a word as regards telegraph and telephone instruments. In these instruments it was impracticable

to avoid the use of wood, but all woodwork must be dovetailed or screwed together, and no reliance whatever could be placed on glue. Also the instrument must be so designed that its proper working was quite independent of any warping or shrinking of the wood which might occur. He stated that they had in the Telegraph Department used german-silver wire for their resistances, and found it last very well. They were, however, now experimenting with some of the other materials on the market. Mr. Simpson.

Mr. H. H. REYNOLDS remarked that the condition of cases on receipt depended very largely on the time of the year when they came through the Red Sea. The manufacturers insisted on using straw to a large extent, and in hot weather it invariably rotted and caused damage. He had had a case where a few straws fell and adhered to a greased shaft, and when opened in Calcutta the rust had eaten into the steel. He quoted a case of a large engine packed in England for transit to Calcutta, which was fixed into the packing case by wedges driven in between the cylinder lagging and the case, with the result that considerable damage was done. The speaker believed American packing to be the best, and suggested that this might be due to the extremely rough handling which cases received in America, as pointed out in the paper. He stated that nearly all the ordinary types of instruments rapidly deteriorated when kept in Calcutta; so that after a short time it was not unusual to find inaccuracy amounting to 5, 10, or even 20 per cent. In one case a potentiometer was sent out to him packed in such a way that when opened up it fell to pieces, and yet when it was returned to the manufacturers packed in exactly the same way they complained!

Mr. J. C. SHIELDS was glad to see attention drawn in Professor Brühl's paper to the indifferent way in which instruments sent out from home were sometimes packed. The matter was of great importance in India, and he hoped manufacturers at home would take note of the author's remarks. He remembered on one occasion some delicate instruments being sent out by a firm in Paris. They had been most carefully enclosed in a tin-lined case; but the packing consisted of straw which had not been dried. The instruments were in consequence subjected on the way out to a vapour bath for several weeks, and all the iron parts were a mass of rust. Mr. Shields.

Mr. J. WILLIAMSON remarked that the best way of keeping cases the right side up during transit was to fix battens underneath them, which would lend themselves to the shifting of the case on rollers and which would show better than any label how the case was intended to be placed. In the case o instruments he suggested that it might be possible to avoid damage due to moisture during transit by enclosing a small quantity of calcium chloride in a special cover inside the box, as was done by manufacturers of sensitive photographic papers. Mr. Williamson.

Mr. A. H. POOK said that the Home Institution appointed committees for the purpose of considering all sorts of matter of interest to manufacturers, and he was sure that if they would appoint one on the science of packing for export they would be not only doing the home people a good turn, but would assist users and consumers living abroad Mr. Pook.

Mr. Pook. a great deal in a way which ought in some way to recompense them for our late increase in annual subscription and curtailment of our free literature.

Mr. Meares. Mr. J. W. MEARES said that judging by previous speakers and by the experiences one constantly heard of, the packing question was at the root of the whole matter, and he thought we should take steps to place this most interesting paper and discussion before the home manufacturers, so as to advise them of their shortcomings. Where coolie transit of goods was necessary in the hills, foreign manufacturers would undertake to keep the weight and size of nearly all packages within reasonable limits for the purpose, but the British manufacturer knew better and made not the least effort in this direction, with the result that much damage was sustained. It might be noted that natives of this country had not the remotest notion of shifting heavy packing cases by means of rollers and bars, or of opening the lids by recognised methods. If these points were fully considered something would have been gained in the way of making the packing suitable for the treatment it was likely to receive. Again, it was no uncommon thing for a steel shaft to be packed without any protective grease or paint, and as likely as not the case in which it was enclosed would be extremely damp, so that the fact of soldering it up was not of the least good. As an endeavour to meet the trouble which every one experienced in the rainy season, he had constructed a large drying box in which to keep some of his special instruments during that season, and in a tray at the bottom he was putting calcium chloride to dry the air. The case was made to close on thick felt, so that he hoped it would also entirely prevent the ravages of rats and insects.

Mr. McIntyre. Mr. A. N. MCINTYRE said that he did not know whether any of the members of the Calcutta section had experienced the trouble he had had with the reddish enamel finish given to portable Weston instruments; it became spotted and dull-coloured in patches on exposure. The case was of brass and there was no reason why it should not be lacquered, which though not rendering it proof against climatic influences would at least be preferable to the enamel.

The portable Kelvin-voltmeters supplied us were to all appearances either encased in aluminium or aluminised iron; if it was the latter he could not say much for the process as a corrosion-resisting agent, whatever it might do for iron in contact with salt water. The author of an article in one of the Electrical papers recently referred to an almost perfect solder for aluminium, but unfortunately did not give its composition. While speaking of solders he would ask if the author saw any objection to the use of soft bismuth solder fusing at 320° F. for repairing galvanometer suspensions, since it greatly simplified the task. He had tried it on one of his galvanometers with very fair results, though of course it would not do for resistance coils.

Father Lafont. The Very Rev. Father E. LAFONT (*Chairman*), in closing the discussion, said that most of the remarks which he intended to make on this very interesting paper had been forestalled by other speakers. He had thirty-five years' experience in the care and use of instruments in India, and he suggested that it would be highly desirable that the

Local Section should move the I. E. E. to take up the question of inducing manufacturers to attend to the special needs of India. Father Lafont.

The legs of statical instruments should on no account be fixed on with shellac, and in this point the manfacturers failed to appreciate the difference of climate between Europe and India.

As regards packing, Father Lafont considered that it would be better always to get instruments out in parts and to set them up in India, since the users of electric instruments would generally be competent to do this, or should be so; the makers would then perhaps learn to pack the separate parts so as to be immovable, and he would suggest that they should give their packers a course of lectures on the subject of *inertia*, which they seemed generally to ignore.

As regards rubber tubes and stoppers he enquired if there were any satisfactory method of keeping them. [Professor Brühl here suggested glycerine as a preservative.] He stated that for ebonite, darkness was essential. With reference to a previous speaker's remark he suggested that the decomposition of unpolished ebonite would be greater than that of the polished article, as the rough surface, being less dense and hard, would probably be more easily disintegrated by exposure.

Professor BRÜHL in reply, after referring to the remarks of several speakers, said the chief advantage of using ebonite in an unpolished state, especially in the case of corrugated supporting pillars, was that one could always get a fresh and highly insulating surface by giving it a few touches with fine glass paper. Prof. Brühl.

Some German makers had adopted, for the purposes of articles specially manufactured for tropical countries, what they called a tropical outfit, which he could highly recommend; all metal parts were strongly nickelled, and any Nicol's prisms, which, for instance, might form adjuncts of photometric apparatus, had their calcspar rhombs protected by cover-glasses cemented on with Canada balsam.

It was quite possible that light had something to do with the rapid deterioration of certain kinds of material; but he was under the impression that the influence of light was often exaggerated, especially where, as in Bengal, the sky was commonly covered with a haze, which was almost certain to absorb a considerable percentage of active rays. Several instances of destruction which he had heard described as due to the action of light could almost with certainty be traced to the action of dampness and fungoid growths.

For years he had used a device to keep dry one of his balances as well as a Clifton electrometer. He had replaced the top of the balance case by a shallow box having a perforated bottom, and placed shallow trays containing pieces of fused calcium chloride in the box. The electrometer he had housed in an outer case with a similar top to it. Materials for drying the air should be placed on top; materials for absorbing carbonic acid should be kept at the bottom. As concentrated sulphuric acid began to dissociate at about 30° C. with the formation of volatile sulphuric anhydride, sulphuric acid should not be used in India as a desiccating agent, just as it could not be used for the greater part of the year as an absorbent of water vapour in chemical analysis.

Prof. Brühl. As regarded dynamos, the chief trouble one had was about insulation. He should advise his friends to specify that armatures and field magnet coils should have every layer of conductors well painted with good shellac varnish or some equally effective composition, and after finishing to have them well baked. If this were done, and if in India the dynamo were properly housed, he did not think there should be much trouble about the insulation breaking down. But there was no good *complaining* about heat and dampness and nitre, and so on. They had plenty of them and to spare; but as practical politicians they must take means to circumvent those injurious agents. If they placed a motor in a pit which was liable to be flooded, they must not blame Providence if the pit did get flooded and the armature burnt out in consequence. If they placed a dynamo in a shed, a couple of inches above a mud-floor and with no possibility of air-circulation, they must not be astonished if the dynamo got ruined by dust, dirt, dampness, and other damaging influences. Damp surroundings produced consumption even in electric machinery.

He did not believe that the life of a good accumulator cell, provided the cell were carefully treated, was much shorter in India than in Europe. But he too had had a fearful experience with a battery. The type of cell was not the kind he had specified, although it was a cell the praises of which had been sung by more than one English authority and in more than one text-book. Luckily the company who manufactured that battery went into liquidation soon after and could do no further harm. But his battery was really a sight worth seeing, after it had been working for six weeks; every positive plate had buckled into the shape of a cocked hat; and one might straighten them, but in a few days there was the cocked hat again. Of course, he had always been very careful about maximum charges and discharges; his battery had been in work practically without interruption, and he had never allowed it to stand without its being charged up at frequent intervals.

He would like to point out to those who had to order instruments the advisability of completely specifying their requirements. After all they must not expect home firms to find out themselves everything about the tropics. When ordering thermometers, he always specified that the capillary tube must end in a small reservoir of a sufficient capacity to receive the overflow mercury up to a temperature of 45° C. He had nearly always found the firms from whom he had obtained instruments ready to receive suggestions and to act on them. Now and then one did come to deal with a firm who thought that they had nothing to learn; but as soon as he found that out, that firm obtained no further orders from him. On the other hand he knew of firms who had made special experiments on wood suitable for tropical climates. There was one firm who had taken a great deal of trouble in trying to evolve a safe system of packing dynamos for shipment to distant countries. Among the worst offenders were the packers of such things as switches, fuses, etc., anything especially that had porcelain parts. It was very easy to pack these articles so that they could be damaged during transit. The principle which should be acted on in packing fragile articles was to fix them rigidly to some rigid support, but to have

Prof. Brühl.

the supporting frame suspended from or supported by springs, the frame being protected from excessive vibrations by layers of fine shavings. He had spoken about the probable influence of the sea voyage. In most cases, however, the mischief was clearly traceable to damp straw or shavings. Straw should be prohibited as a packing material. If possible, one should order one's goods to be sent off from Europe between May and September, or at any rate at a time when there was no slush or soft snow on the ground. He found that the packing cases were filled with what looked like stable litter whenever the case had been despatched during the winter months. In any case he joined with his *confrères* in the expression of the hope that the Parent Society might be moved into seriously taking up the subject of packing for shipment to distant countries.

MANCHESTER LOCAL SECTION.

COMPARISON BETWEEN STEAM- AND ELECTRICALLY-DRIVEN AUXILIARY PLANT IN CENTRAL STATIONS.

By C. D. TAITE, Member, and R. S. DOWNE, Associate Member.

(Paper read at Meeting of Section on April 7th, 1903.)

Although the competition for economy in the working of Electrical Generating Stations has now become exceedingly keen, yet the widely different figures obtained annually as the result of the year's working of the many generating stations now in existence lead one to believe that other factors besides the price of fuel and the personnel of the staff affect the figures to a very appreciable extent. The authors are of opinion that the choice of auxiliary plant, for instance, may exercise a strong influence for economy or otherwise, according as the selection has been made, wisely or the reverse; they have therefore endeavoured in this brief paper to put forward some results obtained from plant under normal everyday conditions, in the hope that the figures given, being such as can be obtained from similar plant in any generating station and not the result of full-load tests only, may prove of some practical utility to those who from time to time are called upon to purchase central station auxiliary plant.

That the subject embraces a wide variety of machinery may be seen at once from the following list of auxiliary plant to be found in the majority of stations of fair size, and which are driven by steam engines or electric motors:—

Air Pumps for Condensers.	Economisers.
Cranes.	Coal Elevator.
Feed Pumps.	Ash Conveyor.
Mechanical Stokers.	Workshop.

During recent years it has become the practice to use electric motors almost exclusively for driving the greater number of the above adjuncts of the generating station; for instance, cranes, stokers, economisers, coal elevators, ash conveyors, and workshop are generally now found driven electrically; but condenser air-pumps and also feed-water pumps still adhere to a large extent to steam power; the latter two auxiliaries are running continuously, the running of the others being of an intermittent character. It is, however, becoming increasingly recognised that, quite apart from the power required for driving the plant, the loss from condensation in long ranges of steam piping which are rendered necessary when steam auxiliary plant is used is quite appreciable, and compares badly with the small amount of power

absorbed in the cables of an electrical installation. Another important advantage which electrical methods of driving have over steam power is the ease with which the power taken in the former can be measured, while in the case of steam it is next to impossible to state definitely what is the percentage of power absorbed by the auxiliary plant. In the new generating station of the Salford Corporation, where the whole of the auxiliary plant is driven electrically, it is found that the percentage of power absorbed by the auxiliary plant varies from 8·3 per cent. to 6·5 per cent. of the total power generated, according to the state of the load factor; it is clear that the better the load factor the lower will this percentage be reduced. The following figures are those of an average week taken from the station records:—

TABLE I.

		Percentage of Units Generated.
Units Generated	148,851	
Units used on Works	9,687	6·50
Made up as follows:—		
Condensing Plant	6,962	4·67
Boiler Feed Pumps	1,758	1·18
Mechanical Stokers	555	0·37
Ash Conveyor	110	0·07
Economiser Scrapers (1,600 Pipes)...	157	0·11
Coal Elevators...	76	0·05
Workshop	65	0·05
Engine-room Crane	4	—

The power taken by the mechanical stokers represented 1·04 units per boiler-hour, which is a rather higher figure than that obtained in many previous weeks, while the economisers required 0·33 unit per hour for driving the scrapers for each battery of 400 pipes; the coal elevators absorbed 0·22 unit per ton of coal raised 40 feet and deposited in the bunkers. The load factor for the week was 39·1 per cent. $\left(\frac{\text{Units generated} \times 100}{\text{Max. load} \times \text{No. of hours in week}}\right)$; as all the power circuits in the works are metred, it will be seen at once how easily one can check the whole of the power taken by the auxiliary plant when that plant is driven electrically; if in any week abnormal figures are obtained, it is a very simple matter to find the cause, as the weekly or even daily returns show clearly on which plant the abnormal consumption is taking place. This fact in itself tends to promote economy, as one soon finds out whether the plant is giving the duty that may fairly be expected from it; a standard of efficiency can thus be set up beyond which the plant must not be allowed to fall.

To turn now from a general comparison to an individual case, it will be generally admitted that there is no more important auxiliary plant in a generating station than the feed pumps; for, unless the pumps are reliable and trustworthy, the supply of steam for the main engine cannot be guaranteed. It is therefore a matter of the utmost importance to make a correct choice of the type of feed pump.

The points which have to be considered are—

1. Reliability.
2. Economy in working.
3. First cost.
4. Upkeep.

Reliability.

Provided that the plant is ordered from experienced firms, there need be no doubt about the reliability of feed pumps, whether they be driven electrically or by steam; both types are equally satisfactory on this score. Those who have any doubt as to the absolute reliability of electric motors have only to consider the case of the tramcar motor, which is working under the most difficult and trying conditions, yet a breakdown of a tramway motor is quite a rare occurrence. How much more reliable, therefore, should a pump motor be which is working under conditions so much more favourable. Nothing more requires to be said to show that, whether the pumps be driven by steam or by electricity, there need be no question as to any want of reliability.

Economy in Working.

Until the advent of the electric motor, steam pump makers appear to have devoted all their attention to making their pumps reliable, and to have left the question of efficiency to look after itself; lately, however, owing to the competition of the motor and to the much improved figures obtained by electric driving, they have been compelled to seriously consider their position, with the result that steam feed pumps can now be obtained which give results immensely superior to those of a few years ago. Still, owing to the nature of the work which they have to perform, steam feed pumps can never compare in efficiency with the main engines installed in the generating station for generating electricity. One well-known firm of pump makers state the steam consumption of their standard 6,000-gallon pump to be as follows:—

Table II.

Gallons delivered.	Lbs. of Steam used per Hour at 160 lbs. pressure.	Lbs. of Water delivered per lb. of Steam used.
1,000	130	77
2,000	253	79
4,000	490	81·5
6,000	714	84

Tests have been carried out at Southport on pumps which have been in use for three or four years, and the following was the average result of several tests each extending over twenty-four hours under ordinary working conditions:—

Lbs. of water delivered per lb. of steam used ... 49·1

The pumps had been recently thoroughly overhauled and fitted with new pump rings; the great discrepancy, therefore, between the figures obtained and those given by the pump makers must be due to the intermittent character of the load, which was at the average rate of 1,460 gallons of water pumped per hour.

At the Salford station tests have been carried out on an electrically-driven 4,000-gallon pump with the following results :—

TABLE III.

Gallons delivered.	Duration of Test.	Units used.
(1) 8,971	4 hours	27·6
(2) 15,822	4 „	36

If each unit is taken as requiring 30 lbs. of steam to generate it, which is more than 25 per cent. above the full-load consumption of the steam engines installed, the above figures may be stated as follows :—

TABLE IV.

Gallons delivered per Hour.	Lbs. of Water delivered per lb. of Steam used.
2,240	108
3,955	147

Comparing these figures with the figures given above, it will be seen at once how greatly superior the electrically-driven pumps are from the point of duty per lb. of steam than are the steam pumps, and this too in spite of the fact that the full-load overall efficiency of the electrically driven pumps was only 60·67 per cent. The motor in this case was coupled to the pump through worm gearing, which at the time of the test was, comparatively speaking, new, and which is certainly giving better results now. The ratio of the gearing is 12 to 1. It would be interesting if some one could give particulars of tests of pumps electrically driven through spur gearing or by other means.

With regard to the figures obtained at the Southport works, it will be seen that they compare very badly with the electrically-driven plant, and on the basis that the latter absorbs 1·18 per cent. of the total output of the station, the former must be requiring from 2½ per cent to 3½ per cent. of the total output. This is a serious matter, particularly where the price of coal is high, for it is unnecessary to point out that the higher the price paid for fuel the more important does it become to instal economical plant.

The figures given by the pump makers are interesting as showing how slight is the increase in efficiency of a steam pump from light load to full load. The electrically-driven pump, on the other hand, delivers 36 per cent. more water per lb. of steam at full load than it does at half load. This points to the desirability of a careful sub-division of plant where electric motors are adopted.

FIRST COST.

With regard to the money value of the saving in power, this varies directly with the price of fuel, and inversely as the first cost of the plant. In Lancashire, where good slack can usually be obtained for 8s. 6d. to 9s., the money value of the steam saved is less than half what it would be in London and south-country towns, where fuel ranges from 20s. to 30s. a ton.

Still, taking again the Salford figures, 1 per cent. of the present annual coal bill represents £60, and to put the saving in fuel at this station due to the use of electrically-driven pumps instead of steam pumps at £100 per annum is a conservative estimate. Against this saving has to be set the additional interest and sinking fund due to the extra cost of the electrical pumps; say for a 5,000-gallon pump £330, against £125 for a steam pump; allowing 6¼ per cent. in each case and the provision of three pumps, the difference per annum would be £40, which reduces the money value of the saving to £60. This may seem a small sum, but it should be remembered that it represents the minimum saving.

Upkeep.

With regard to the question of upkeep there is little if anything to choose between the motor-driven pump and the steam pumps provided that both are well looked after and kept in a proper condition. Care, however, must be taken to see that the delivery range attached to the pumps is provided with a relief valve of ample area to prevent any damage occurring even should the fireman close all his feed valves; otherwise the effect would be to cause a fracture either of the pipes or the pump casing.

The case, therefore, with regard to feed-pumps may be summed up as follows:—

1. *Reliability.*—Both types equally reliable.
2. *Economy in working.*—The electrically-driven pump shows a great superiority.
3. *First cost.*—The electrically-driven pump costs about three times as much as the steam pump.
4. *Upkeep.*—Both types satisfactory.

Generally speaking the authors are in favour of electrically-driven feed pumps, particularly in localities where coal is dear. Where such pumps are used, and in fact where any electrically-driven auxiliary plant is extensively adopted, the authors consider that a battery of accumulators is a practical necessity, as in the event of a total breakdown of the generating plant from any cause, the supply of water to the boilers and the lighting of the works would not be interrupted.

Turning now to the consideration of condensing plant, it will be seen from Table I. that the condensing plant at the Salford works absorbs no less than 4·67 per cent. of the total output of the station.

The plant consists of eight sets of jet condensers each provided with an Edwards three-throw air-pump driven electrically through double reduction spur gearing. Each condenser deals with the steam exhausted from a 1,200 H.P. engine, and the water for condensing this steam is drawn from the Manchester, Bolton and Bury Canal. One of the conditions being that the temperature of the discharge water shall not exceed 90° Fahr. it is frequently necessary to use a rather excessive amount of circulating water. The percentage of power taken by the condensing plant when the engine is working fully loaded is 2·4 per cent. This compares with 1½ to 2 per cent. which is the usual allowance when the air-pumps of a jet condenser are driven direct from the

main engine as in mill work; the latter practice is undoubtedly the most economical, as the losses in the dynamo and motor are both saved; but with the modern high-speed engine a direct-coupled condenser is, generally speaking, impracticable, and the choice lies between a separate steam engine and an electric motor. The latter is generally the most convenient to adopt on account of cleanliness and small space required, but the advantage with regard to economy in power rests, if anything, with the steam plant run condensing. Where surface condensers are used the conditions favour the use of electric motors, and the authors recommend their more frequent adoption.

At Southport interesting figures have been obtained in connection with the use of single-phase alternating-current motors driving Gwynne centrifugal pumps for raising water for Korting's ejector condenser. The total lift is 35 feet, the volume of water lifted is 60,000 to 66,000 gallons per hour per engine, and the horse-power of the motors is 35 B.H.P.; the engines to which the condensers are attached are of 1,000 H.P.; during a three hours run the alternator generated an average of 510 units per hour, full load being 600 k.w., and the motor pump took 29·6 units per hour, 5·8 per cent.; the percentage power, however, during the evening's run, averaged as much as 7·26 per cent. of the units generated. As the condensing plant requires a constant supply of water irrespective of the load on the engine, it is evident that when the alternator is generating its full load (600 k.w.), the percentage of power taken by the condenser would be reduced to 4·93 per cent., still a high figure.

A last example of an electrically-driven plant is a motor alternator set at the Salford Corporation Works, used for supplying the outlying districts with alternating current. There are two sets in duplicate, each consisting of a 150 k.w. direct-current motor, direct-coupled to two 120 k.w. alternators; the latter is of an old-fashioned design, having been built in 1894. The two sets are never run together except for the purpose of changing from one to another; one set just takes the full load every night, but during the daytime the load is very light. The average daily efficiency taken over several weeks in the winter amounted to only 72 per cent., the load factor of the plant being 35 per cent.; the maximum full-load efficiency is 84 per cent. This example is given to show the care which must be taken in designing a direct-current supply from an alternating-current generating station when a reasonable efficiency is to be obtained.

A few figures relating to eleven months' working of the auxiliary plant at Salford may be interesting. The total units used during this period by the auxiliaries amount to approximately 410,000, equivalent to 7·0 per cent. of the total units generated; as the cost of fuel is just 0·25d. per unit generated, the money value of the units is £427. There is no doubt that the auxiliary plant is partly responsible for the low coal cost per unit generated, as it has helped to improve the load factor very materially of the generating plant.

Managers of electricity undertakings spend a large proportion of their time in advocating the adoption of electric motors in the interests of the consumer, and with a view of improving the station load factor;

consequently, it is essential that wherever possible they should arrange for electrical driving on their own works.

In conclusion the authors feel that they must apologise for so frequently quoting the figures of the stations with which they are connected; they have been compelled to do so owing to the paucity of other information at their disposal; they trust, however, that their remarks may serve the purpose of eliciting information from other central station engineers with a view of ventilating a subject with regard to which reliable data is not at present easily available.

MANCHESTER LOCAL SECTION.

THE CARRIAGE OF GOODS ON ELECTRIC TRAMWAYS.

By ALFRED H. GIBBINGS, Member.

(Paper read at Meeting of Section, April 21st, 1903.)

The many questions involved in the carriage of goods have always been of supreme importance to manufacturing communities in all countries. At the present day when keen international competition is so strong, every improvement in the direction of economy of both time and cost gives an immediate advantage where it is adopted. I need only refer to such a scheme as the Manchester Ship Canal in the illustration of the enormous importance attaching to this subject. But we are not concerned in this paper with the various methods and details of long-distance transit. For long distances both railway and canal carriage are at present essential, and it is true of each that an increased through traffic and lessened local traffic would tend to cheapen existing rates. On the other hand, neither railway nor canal will ever be capable of such extension as to avoid the necessity for the subsidiary use of carts or other vehicles for the collection and distribution of goods, and it is these charges which so largely increase the cost of transportation.

The charges and rates which are at present levied for long-distance transmission may be likened to the reduced charge for electric energy possible only to the long-hour consumer on an electric lighting system. In these cases the "standing charges" rate is reduced in proportion to the length of route or time respectively. A similar analogy exists between the short-distance charges for conveyance of goods by railway, road, or canal, and the short-hour electric light user. Each has to bear a large proportion of the "standing charges" rate. These "standing charges" in the case of goods conveyance consist of heavy interest on rolling stock due to the very low earning capacity on short runs, increased proportion of handling and transhipment costs, station terminal charges, warehousing, etc.

Some of these charges are, of course, bound to occur with any system of handling and transporting goods, and the nature of the goods has also to be taken into consideration, but I propose to show in this paper some of the possibilities of cheapening the cost of conveyance by utilising electric tramway and light railway systems. By the term "short-distance traffic" I refer to conveyance up to fifty miles, but particularly to distances varying from five miles to thirty miles.

AREAS OF CONNECTED TRAMWAY SYSTEMS.

In order to inaugurate and carry on successfully such a scheme, it is necessary to have a considerable area covered by tramways with tracks of uniform gauge. Such an area is illustrated in Fig. 1.

This area includes the following lines, viz. :—

Liverpool Corporation	Gauge 4 ft. 8½ in.
Liverpool and Prescot Light Railway	„ 4 ft. 8½ in.
St. Helens Tramways (Leased by the Corporation to a Company).	„ 4 ft. 8½ in.
South Lancashire Tramways ...	„ 4 ft. 8½ in.
Wigan Corporation...	„ 3 ft. 6 in.
Bolton Corporation	„ 4 ft. 8½ in.
Bolton, Turton and Darwen Light Railways	„ 4 ft. 8½ in.
Darwen Corporation	„ 4 ft.
Blackburn Corporation	„ 4 ft.
Accrington Corporation	„ 4 ft.
Farnworth Urban District... ...	„ 4 ft. 8½ in.
Radcliffe Urban District	„ 4 ft. 8½ in.
Whitefield Urban District... ...	„ 4 ft. 8½ in.
Bury Tramways Company... ...	„ 4 ft. 8½ in.
Rochdale Tramways Company ...	„ 3 ft. 6 in.
Warrington Corporation	„ 4 ft. 8½ in.
Salford Corporation...	„ 4 ft. 8½ in.
Eccles Corporation	„ 4 ft. 8½ in.
Manchester Corporation	„ 4 ft. 8½ in.
Oldham, Ashton and Hyde Tramway Co.	„ 4 ft. 8½ in.
Stalybridge, Hyde, Mossley and Dukinfield Tramways and Electricity Board	„ 4 ft. 8½ in.

Notwithstanding the very complete system described above, it will nevertheless be apparent from the map that much yet remains to be done to reach many of the mill districts, collieries, and outlying townships in order to obviate as far as possible the cost of transhipment, handling, and cartage.

Some considerable attention has already been given to the carriage of goods on electric tramways, the first proposal emanating through the Liverpool Chamber of Commerce in a scheme submitted by Mr. J. T. Wood on October 14, 1896. Mr. Wood says :—

"It is necessary that I should now point out to the Committee that no new departure or principle is involved in the proposal to use tramways for the carriage of goods, nor would it be necessary, in obtaining powers for the proposed tramways, to get any special permission to use them in that manner . . . The goods and materials for which charges may be made are specified in a minute way, and include, for instance, coal, lime, iron, bricks, castings, sugar, grain,

corn, flour, cotton, wools, fish, etc. A charge is also prescribed for iron boilers, cylinders, and articles of great weight. No objection could, therefore, be raised to the scheme on the ground that it was intended to use the tramway in a way which has not been contemplated by the Legislature; in fact, the general tendency of legislation during the past few years has been in the direction of furthering the trade of the country by the construction of light railway systems."

In referring to this scheme of Mr. Wood's, I must include among the preliminary movements made in the United Kingdom to put into practical effect light railways for goods traffic, that of the inquiry of the Liverpool Chamber of Commerce, whose report, issued on July 22, 1898, embodies no less than twelve proposals for the transportation of goods between Liverpool and Manchester and adjacent centres. The report contains the discussion on each scheme, and a summary of the advantages and disadvantages of each.

In April, 1901, I prepared a detailed report on the subject so far as it applied to the area of the South Lancashire Tramways, and also a special contribution to *Traction and Transmission* in April and May, 1901. During the last two years the following literature has also appeared on the subject:—

"The Conveyance of Goods on Electric Trolley Lines," by A H. Gibbings; paper read before the Liverpool Engineering Society on January 29, 1902.

"Parcels on Tramways," *Manchester Evening Chronicle*, December 16, 1902.

"Goods Traffic on the Tramways,' *Manchester Guardian*, February 12, 1903.

"Electric Trams and Goods Traffic," *Manchester Guardian*, November 22, 1902.

"Through Traffic on Tramways for Passengers and Goods," paper read before the Liverpool Chamber of Commerce July 21, 1902, by J. E. Waller.

"Running Powers," by A. H. Gibbings; paper contributed to *Traction and Transmission*, April, 1902.

"Some Notes on the Commercial Management of Electrical Tramways," by T. W. Sheffield, *Fielden's Magazine*, January and February, 1903.

"The Commercial Management of Electrical Tramways," by C. H. Wordingham, *The Electrical Review*, January 30, 1903.

"The Conveyance of Goods on Electric Trolley Lines," by A. H. Gibbings, paper read before the British Association, Glasgow, 1901.

The following publications also refer to various methods of dealing with goods traffic:—

"Report of a Special Committee on Light Railways," Incorporated Chamber of Commerce of Liverpool, July 22, 1898.

"Plateways," by Alfred Holt, Liverpool Printing and Stationery Company, Ltd., 42, Castle Street, Liverpool, 1899.

"Heavy Motor Traffic in France," by M. Georges Forestier, The Journal of Commerce Printing Works, 9, Victoria Street, Liverpool, 1900.

"Light Railways," by J. Walwyn White, F.I. Inst. Widnes, 1895; paper read before the Liverpool Chamber of Commerce and the Society of Chemical Industry.

"A New System of Heavy Goods Transport on Common Roads," by Bramah Joseph Diplock; Longmans, Green & Co., 39, Paternoster Row, London, 1902.

"Supplementary Report of the Special Committee on Light Railways," Incorporated Chamber of Commerce of Liverpool, Lee and Nightingale, 15, North John Street, Liverpool, 1900.

"Light Railways and Agriculture," *Electrical Investments Review*, Wednesday, February 4, 1903.

In the foregoing publications many aspects of the question have been put forward and discussed, and to a certain extent, therefore, the rough ground has been broken. Reference to these papers should be made for many interesting features and expressions of individual opinion which it is impossible to embody herein. For instance, in the writer's paper read before the Liverpool Engineering Society in January, 1902, the discussion included remarks by Mr. Brierley H. Collins, M.Inst.E.E., Mr. Alfred Holt, M.I.C.E., Mr. J. E. Lloyd Barnes, Wh. Sc., M.I.Mech.E., and Mr. John A. Brodie, Wh. Sc., M.I.C.E., M.I.Mech.E. (the City Engineer of Liverpool), and others.

Existing Methods and Cost of Conveying Goods.

The usual methods of goods conveyance at the present time are by railways, canals, automobiles, and horse-drawn vehicles. Railway companies have for too long had the sole control of goods traffic. The full use of existing canals, and the possible construction of others, would be a step in the direction of economy.

Some attempt has recently been made under the Locomotion on Highways Act, 1896, to reduce the cost of conveyance of goods between railway and canal depôts and the mills, warehouses, etc., by automobiles, and an excellent paper on that subject was read before the Liverpool Self-Propelled Traffic Association on December 3, 1900, by M. Georges Forestier, who is engineer-in-chief to the Department of Roads and Bridges in France.

The principal method, however, of such local conveyance is by horse-drawn lurries. At the Stalybridge railway goods depôt, for instance, no less than 26 lurries are required to deliver cotton, coal, and other goods to the various mills within the district. At Hyde 42 are required, at Mossley 14, and at Dukinfield 10, and in each of these cases the lurries are owned by the railway companies.

Table I. gives a list of imports and exports into and from Liverpool respectively for the years 1898 and 1899. These figures represent the quantities of goods actually conveyed through Liverpool, exclusive of those which find their way by the Ship Canal direct to the Port of Manchester, the statistics of which are, of course, separately kept by the Custom House authorities as for any other port. I have, however, considered that the Liverpool statistics are in themselves amply sufficient to illustrate the enormous goods traffic in the area described

TABLE I.—TRADE OF LIVERPOOL.

IMPORTS.

Goods.		Year. 1898.	1899.
ARTICLES OF FOOD AND DRINK.			
Bacon...	cwt.	2,999,624	2,836,703
Beef	„	1,996,830	2,338,541
Butter...	„	82,504	166,334
Cheese	„	629,386	556,979
Cocoa	lbs.	3,763,275	9,993,140
Corn and Flour ...	cwt.	44,705,116	49,073,980
Currants	„	457,574	532,938
Eggs	gt. hund.	667,687	606,785
Farinaceous substances	£	279,170	372,265
Fish	cwt.	602,001	627,728
Fruit	£	1,853,684	2,017,264
Hams	cwt.	1,347,582	1,355,374
Lard	„	909,107	934,196
Milk, condensed ...	„	55,133	56,509
Mutton	„	884,450	848,273
Oil, seed cake ...	„	116,596	134,862
Onions	bush.	1,701,378	2,242,557
Pork	cwt.	393,132	388,142
Potatoes	„	262,444	173,839
Raisins	„	234,901	249,460
Rice	„	1,929,165	2,577,339
Pepper	lbs.	760,228	558,786
Spirits	gall.	1,957,065	1,788,811
Sugar	cwt.	7,510,677	6,559,362
Vegetables, raw ...	£	209,219	211,469
Wine	gall.	2,795,547	2,800,626
METALS.			
Copper	tons	68,300	70,301
Iron	„	87,899	128,091
Lead	„	23,240	24,949
Pyrites	„	178 620	204,243
Quicksilver	lbs.	36,185	6,000
Tin	tons	19,860	27,547
Zinc	„	13,061	10,826
RAW MATERIALS.			
Caoutchouc	cwt.	382,947	336,340
Cotton, raw	„	16,184,362	11,855,495
Hides	„	220,476	297,230
Leather	„	325,837	368,873
Manures	tons	85,677	135,672
Oil, cocoanut & palm,	cwt.	948,119	1,061,606
Paper...	„	241,280	245,945
Paraffin	gall.	188,578	224,036
Petroleum	„	33,565,369	32,490,846
Skins	No.	6,724,212	7,591,634
Tallow	cwt.	621,516	598,643
Tobacco	lbs.	49,284,906	74,307,882
Wood	loads	719,550	797,846
Wool, sheep's ...	lbs.	90,672,043	77,694,198
MISCELLANEOUS.			
Animals, living ...	No.	547,398	533,070
Cork, manufactured	lbs.	2,207,615	2,289,300
Glass manufactures	cwt.	66,041	71,624
Jute „	£	1,043,215	1,102,999
Rosin	cwt.	373,021	577,811

EXPORTS.

Goods.		Year. 1898.	1899.
YARNS AND TEXTILE FABRICS.			
Cotton yarn ...	lbs.	84,967,200	72,738,400
Cotton manufactures	yds.	3,511,282,600	3,640,632,700
Jute yarn	lbs.	7,839,000	7,061,900
„ manufactures	yds.	32,287,800	31,827,500
Linen yarn ...	lbs.	3,472,900	4,239,900
„ manufactures	yds.	80,497,200	102,030,000
Woollen yarn ...	lbs.	1,536,400	1,734,600
Woollen manufactures	yds.	64,284,600	66,814,900
METALS.			
Brass	cwt.	36,331	32,838
Copper	„	253,964	272,066
Iron...	tons	736,533	782,072
Lead	„	2,244	1,959
Tin	cwt.	31,279	33 390
Zinc	„	24,619	20,577
OTHER ARTICLES.			
Alkali	cwt.	3,186,100	3,197,200
Bleaching material	„	879,900	1,049,800
Candles	lbs.	6,792,000	11,253,900
Caoutchouc manufactures	£	250,878	231,791
Carriages, railway	£	910,969	1,019,404
Chemical products	£	1,490,891	1,576,362
Coals	tons	848,218	445,180
Earthenware ...	£	1,093,236	1,231,277
Gunpowder ...	lbs.	3,874,800	2,719,700
Machinery... ...	£	4,584,833	5,080,703
Oilcloth	yds.	5,301,800	5,436,700
Salt	tons	494,458	451,058
Soap	cwt.	684,000	799,000
Spirits, British ...	gal.	451,584	437,809
Sugar	cwt.	615,526	493,671
Tobacco, manufactured	lbs.	1,309,110	1,819,070
Wool, sheep's ...	„	3,808,500	9,706,100
Bacon and Hams	cwt.	89,600	87,523
Caoutchouc, raw...	„	211,113	204,285
Corn and Flour ...	„	1,350,861	1,078,191
Cotton, raw ...	„	849,411	1,646,763
„ waste ...	lbs.	4,716,577	6,839,595
Feathers, ornamental ...	„	126,296	81,035
Fish, cured ...	cwt.	113,919	118,603
Fruit, preserved ...	lbs.	4,773,390	2,783,226
Jute manufactures	£	904,332	1,034 548
Oil, palm	cwt.	569,195	599,366
Quicksilver ...	lbs.	240,590	245,641
Rice...	cwt.	1,097,710	1,631,425
Skins	No.	3,228,065	3,868,753
Spices	lbs.	1,210,934	2,129,892
Sugar	cwt.	280,365	188,848
Tobacco	lbs.	7,007,021	4,535,708
Wool, sheep's ...	„	20,914,920	28,935,732

TABLE II.

Railway Rates from Station to Station for various articles from Liverpool to the undermentioned towns.

Town.	Miles from Liverpool.	Class of Goods.											
		Special		1st Class.		2nd Class.		3rd Class.		4th Class.		5th Class.	
		S. to S. charge.	Rate per ton per mile.	S. to S. charge.	Rate per ton per mile.	S. to S. charge.	Rate per ton per mile.	S. to S. charge.	Rate per ton per mile.	S. to S. charge.	Rate per ton per mile.	S. to S. charge	Rate per ton per mile.
		s. d.	d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.
Aintree	5	3 1	$7\frac{2}{5}$	3 6	0 $8\frac{2}{5}$	4 4	0 $10\frac{2}{5}$	5 3	1 $0\frac{3}{5}$	7 0	1 $4\frac{4}{5}$	10 6	2 $1\frac{1}{5}$
Ashton	38	7 10	$2\frac{9}{19}$	9 7	0 $3\frac{1}{38}$	11 4	0 $3\frac{11}{19}$	13 1	0 $5\frac{5}{38}$	14 7	0 $4\frac{23}{38}$	21 0	0 $6\frac{12}{19}$
Denton	$37\frac{1}{2}$	7 10	$2\frac{38}{75}$	8 9	0 $2\frac{12}{25}$	10 6	0 $3\frac{9}{25}$	12 3	0 $3\frac{23}{25}$	15 9	0 $5\frac{1}{25}$	21 0	0 $6\frac{54}{75}$
Dukinfield	37	7 10	$2\frac{20}{37}$	9 7	0 $3\frac{4}{37}$	11 4	0 $3\frac{25}{37}$	13 1	0 $4\frac{9}{37}$	16 7	0 $5\frac{14}{37}$	21 0	0 $6\frac{30}{37}$
Earlstown	$14\frac{3}{4}$	4 4	$3\frac{1}{2}$	5 3	0 $4\frac{16}{59}$	6 1	0 $4\frac{56}{59}$	7 0	0 $5\frac{41}{59}$	12 3	0 $9\frac{57}{59}$	14 10	1 $0\frac{4}{59}$
Fazakerley	5	3 8	$8\frac{4}{5}$	5 3	1 $0\frac{3}{5}$	6 1	1 $2\frac{3}{5}$	7 0	1 $4\frac{4}{5}$	8 9	1 9	15 9	3 $1\frac{4}{5}$
Garston	$5\frac{1}{2}$	4 4	$9\frac{5}{11}$	4 9	0 $10\frac{4}{11}$	5 3	0 $11\frac{5}{11}$	6 1	1 $1\frac{3}{11}$	10 6	1 $10\frac{10}{11}$	13 1	2 $4\frac{6}{11}$
Glazebrook	$24\frac{1}{2}$	7 0	$3\frac{21}{49}$	7 10	0 $3\frac{41}{49}$	8 9	0 $4\frac{2}{7}$	9 7	0 $4\frac{34}{49}$	12 3	0 6	15 9	0 $7\frac{5}{7}$
Gorton	34	7 4	$2\frac{10}{17}$	8 3	0 $2\frac{31}{34}$	9 7	0 $3\frac{13}{34}$	11 4	0 4	14 10	0 $5\frac{4}{17}$	18 4	0 $6\frac{8}{17}$
Guide Bridge ...	36	7 10	$2\frac{11}{18}$	9 7	0 $3\frac{7}{36}$	11 4	0 $3\frac{7}{9}$	13 1	0 $4\frac{13}{36}$	16 7	0 $5\frac{19}{36}$	21 0	0 7
Heywood	$38\frac{1}{4}$	9 7	3	11 4	0 $3\frac{85}{153}$	13 1	0 $4\frac{16}{153}$	15 9	0 $4\frac{144}{153}$	19 3	0 $6\frac{2}{51}$	23 7	0 $7\frac{61}{153}$
Hollinwood ...	36	9 11	$3\frac{11}{36}$	11 4	0 $3\frac{7}{9}$	13 1	0 $4\frac{13}{36}$	14 10	0 $4\frac{17}{18}$	18 4	0 $6\frac{1}{9}$	23 7	0 $7\frac{31}{36}$
Hyde	$38\frac{1}{2}$	7 10	$2\frac{34}{77}$	9 7	0 $2\frac{76}{77}$	11 4	0 $3\frac{41}{77}$	13 1	0 $4\frac{6}{77}$	16 7	0 $5\frac{13}{77}$	21 0	0 $6\frac{6}{11}$
Kenyon Junction ...	$18\frac{3}{4}$	5 3	$3\frac{9}{25}$	6 1	0 $3\frac{67}{75}$	7 0	0 $4\frac{36}{75}$	8 9	0 $5\frac{9}{15}$	13 1	0 $8\frac{28}{75}$	16 7	0 $10\frac{46}{75}$
Leigh and Bedford	$21\frac{3}{4}$	5 3	$2\frac{26}{29}$	6 1	0 $3\frac{31}{87}$	7 0	0 $3\frac{25}{29}$	8 9	0 $4\frac{24}{29}$	13 1	0 $7\frac{19}{87}$	15 9	0 $8\frac{20}{29}$
Manchester ...	$31\frac{1}{2}$	7 4	$2\frac{50}{63}$	8 3	0 $3\frac{1}{7}$	9 7	0 $3\frac{41}{63}$	11 4	0 $4\frac{20}{63}$	14 10	0 $5\frac{41}{63}$	18 4	0 $6\frac{62}{63}$
Mossley	42	8 9	$2\frac{1}{2}$	10 6	0 3	12 3	0 $3\frac{1}{2}$	14 0	0 4	17 6	0 5	21 10	0 $6\frac{5}{21}$
Oldham	37	8 9	$2\frac{31}{37}$	10 6	0 $3\frac{15}{37}$	12 3	0 $3\frac{36}{37}$	14 10	0 $4\frac{30}{37}$	18 4	0 $5\frac{35}{37}$	23 7	0 $7\frac{24}{37}$
Prescot	$7\frac{3}{4}$	4 4	$6\frac{22}{31}$	4 9	0 $7\frac{11}{31}$	6 1	0 $9\frac{13}{31}$	7 0	0 $10\frac{26}{31}$	8 9	1 $1\frac{17}{31}$	12 3	1 $6\frac{30}{31}$
Royton	$40\frac{1}{2}$	9 7	$2\frac{68}{81}$	12 3	0 $3\frac{17}{27}$	14 0	0 $4\frac{4}{27}$	17 6	0 $5\frac{5}{27}$	21 0	0 $6\frac{2}{9}$	23 7	0 $6\frac{80}{81}$
Staleybridge ...	$39\frac{1}{2}$	7 10	$2\frac{30}{79}$	9 7	0 $2\frac{72}{79}$	11 4	0 $3\frac{35}{79}$	13 1	0 $3\frac{77}{79}$	16 7	0 $5\frac{3}{79}$	21 0	0 $6\frac{30}{79}$
Warrington ...	18	4 4	$2\frac{8}{9}$	5 3	0 $3\frac{1}{2}$	6 1	0 $4\frac{1}{18}$	7 10	0 $5\frac{2}{9}$	9 7	0 $6\frac{7}{18}$	13 1	0 $8\frac{13}{18}$
Wigan	19	6 3	$3\frac{18}{19}$	7 0	0 $4\frac{8}{19}$	7 10	0 $4\frac{18}{19}$	10 6	0 $6\frac{12}{19}$	13 1	0 $8\frac{5}{19}$	16 7	0 $10\frac{9}{19}$

although there can be no doubt that a very large distribution occurs at Manchester, both within its own area and those of the districts contiguous.

These figures, of course, take no account whatever, nor give any indication, of the immense local goods traffic within each district or between several districts. It is very difficult to obtain any adequate idea, and still more detailed statistics, of purely local requirements, in this direction, except such as can be gained by direct association with any particular locality. It may, however, be taken as being very considerable.

It will be apparent from these remarks that an enormous number of lurries must be employed to convey goods from the docks to the railway termini. In Liverpool the number of horses used solely for this purpose is about five thousand, and the distance from dock to railway averages about two miles. When the goods arrive on the lurry at the railway terminus it is not always convenient, even there, to tranship directly into the railway truck, and in that case the goods have to be deposited for the time in the shed. Thus two, and sometimes three, handlings are involved before the goods are moved an inch by the railway company, and this condition of affairs gives rise to "service terminal charges." Somewhat similar processes have to be again gone through when the goods arrive at the end of their transit by rail, causing repeated expense and delay before they are actually on the road to the user or consignee. The expense consequent on these complications is naturally heavy in any case, but exceptionally so in regard to conveyance over comparatively short distances. The cartage rates alone* (after payment of dock dues, master porterage, quay accommodation, etc.), between docks and railway termini, may be taken at 1s. 3d. per ton as a representative average for all classes of goods not exceeding two tons in weight for any single piece or article. The station and service terminal charges vary from sixpence to seven shillings per ton from coal to high-class goods according to the grade, and these charges have to be added on to the total cost of conveyance. In Table II. a list is given of railway rates (exclusive of station terminal charges) from Liverpool to various towns within, or adjacent to, the area shown in Fig. 1.

In addition to the economies which will be effected with the electric trolley system, through the reduction in the cost of handling, the avoidance of heavy station terminal charges and other tolls, and the disappearance of carter's charges at least at one end of route, further savings may be anticipated through the higher average weight which it will be possible to deal with per car per mile, and the small capital involved when compared with railway rolling-stock and adjuncts.

The average load of a railway merchandise truck does not exceed three tons. (This statement was given in evidence by Sir George Finlay.)

It may, *per contra*, be very reasonably assumed that with the extra

* For further particulars see Report of Dock Rates Sub-Committee, 1895, and Report of Manchester Ship Canal Special Committee (1894) of Liverpool Chamber of Commerce.

staff required, when no more than two trucks are marshalled together the standing charges will be relatively higher than that of railway companies. But this is only one item in the case after all. As against this we must remember that no expensive and time-absorbing shunting operations are necessary, that no signalling is required, and that each truck will have at least four times the earning capacity of the railway truck, owing to the much more rapid transit and delivery of goods. Careful calculations have been made, and it is found possible to charge, for full loads, only 50 per cent. of the present railway charges, and then leave a sufficient commercial profit. Reference to Table II. will show the present prices under the various classes. Take the instance given on page 1063. The total cost works out to 4⅓d. per ton per mile. If conveyed by electric traction this cost would not exceed 2d. per ton per mile, irrespective, that is in both cases, of the cost of conveyance from the depôt. The saving in time of transit is also very important.

Let us assume the destination is Bolton. By road through Knotty Ash, St. Helens, Abram, Hindley to Bolton the distance is about twenty-nine miles. After allowing for all stoppages an average speed of six miles an hour may be anticipated, and the entire journey would therefore be accomplished in 4⅘ hours. Compare this with existing methods. First of all lurry loads to the railway terminus, then handling of goods a second time in transferring to railway waggons; thence a railway journey involving the marshalling of trucks, shunting, coupling and uncoupling, and after perhaps eighteen hours, arrival at Bolton. Here again there is handling a third time in transferring to lurry, and possibly service terminal charges to pay.

The time which these operations and the entire journey would involve might be calculated to be about twenty-four hours.

As a matter of fact, the basis of calculation and items of cost will average very little different from that for passenger traffic, and the foregoing figures have been arrived at on an assumed revenue of 12 pence per truck-mile. It will be seen that for full loads of ten tons at, say, 2d. per ton, the revenue would be 20 pence.

Proposed Methods of Handling and Transportation.

An ideal scheme for the conveyance of goods from any one part to any other part of such an area as exists in South Lancashire should comply with the following conditions:—

1. The goods should be loaded direct from the docks, warehouses, or depôts, and deposited, without further handling, at their ultimate destination.
2. In order to carry out the above condition, special sidings should be run in to warehouses, mills, etc.
3. There should be no special stoppages or delay in transit from the loading point to the destination.
4. The service, when necessary, should be continuous for the whole twenty-four hours per day, excluding, perhaps, Saturdays, Sundays, and public holidays; but even on these days a service should be available if urgently required.

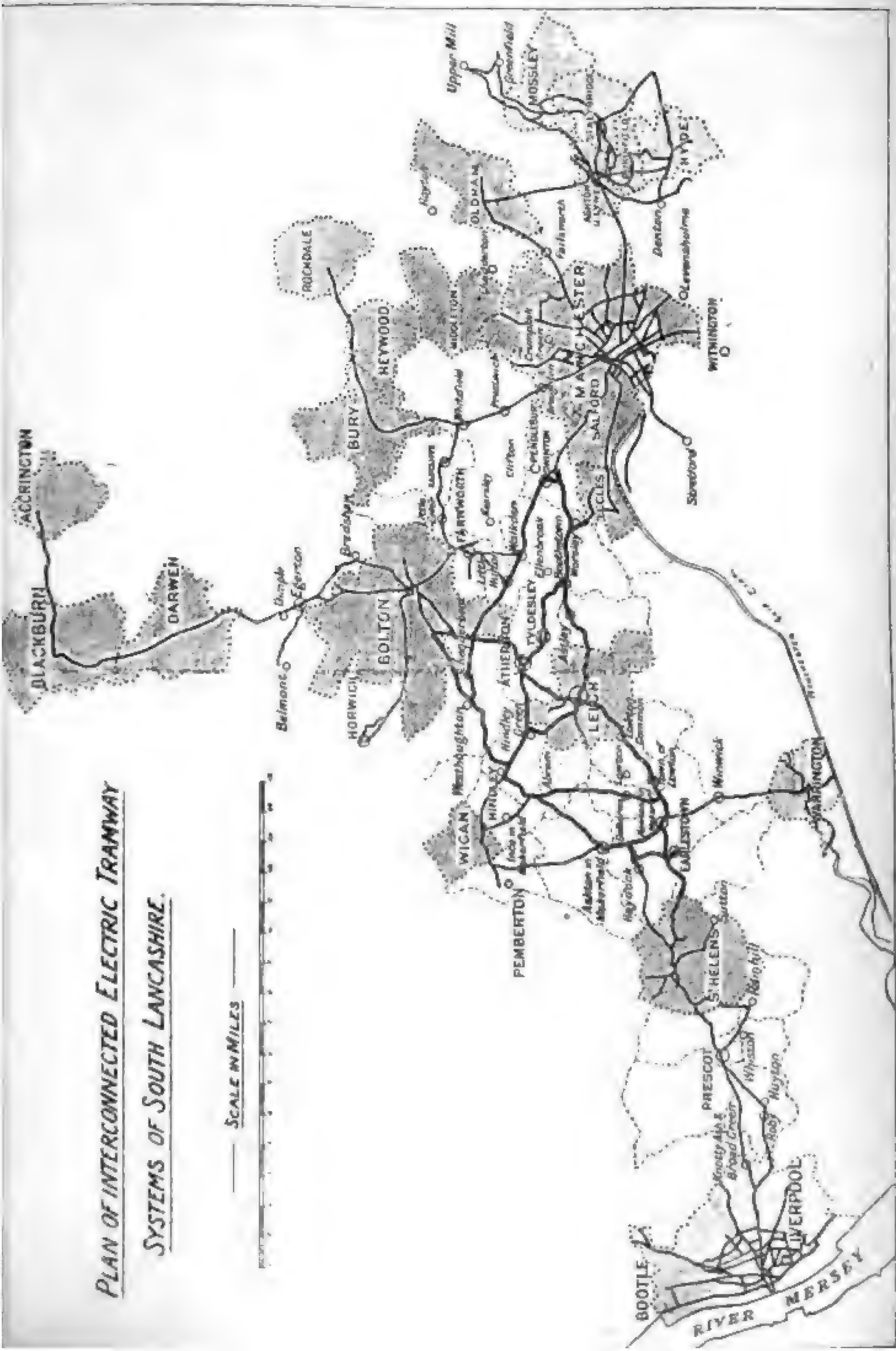

PLAN OF INTERCONNECTED ELECTRIC TRAMWAY
SYSTEMS OF SOUTH LANCASHIRE.
SCALE IN MILES
ACCRINGTON
BLACKBURN
DARWEN
Egerton
Belmont
BOLTON
HORWICH
Bradshaw
BURY
HEYWOOD
ROCHDALE
MIDDLETON
OLDHAM
Royton
Upper Mill
Greenfield
MOSSLEY
STALYBRIDGE
HYDE
Denton
Failsworth
Levenshulme
MANCHESTER
WITHINGTON
SALFORD
Stretford
ECCLES
FARNWORTH
Kearsley
Walkden
Clifton
TYLDESLEY
Ellenbrook
ATHERTON
Westhoughton
Hindley Green
LEIGH
Astley
HINDLEY
WIGAN
PEMBERTON
Haydock
EARLESTOWN
Winwick
WARRINGTON
Sutton
ST HELENS
Rainhill
PRESCOT
Whiston
Huyton
Roby
Knotty Ash & Broad Green
LIVERPOOL
BOOTLE
RIVER MERSEY

Fig. 1.

5. No shunting operations should be necessary, and hence marshalling should be avoided. Not more than two or three trucks should be marshalled together.
6. One or two special forms of trucks should be used for all classes of goods.
7. The service should be expeditious, but not necessarily entailing a high rate of speed.
8. The system should possess every facility for the transference of goods (without handling in piece) to or from railway trucks or horse lurries.
9. The line for the conveyance of goods should not interfere with any passenger or ordinary road traffic.
10. No alteration in the existing gradients of the roadways should be necessary.
11. The maximum weight to be carried on each truck should be not less than nine tons.
12. The charges should be reasonably economical, and should compare more favourably with American and Continental railway rates than the present British railway rates.

In the foregoing list it will be noticed that one of the most essential conditions to ensure economy is the avoidance of loading and unloading between terminals. In other words, wherever transhipment is necessary, the goods should be handled in bulk and not in part. Some attempt has already been made in that direction by certain railway companies. The South Eastern Railway Company have a special arrangement for conveying goods, passengers' luggage, etc., from London to various parts of the Continent without unloading. It consists of a detachable van which rests upon the top of a flat railway truck. This van is provided with steel ropes, by means of which it is lifted by a crane from the truck and deposited on the deck of the steamboat, or *vice versâ*. Fig. 2 shows the van after it has been lifted from the railway truck, and also the relative position of the steamboat, crane, and railway. Fig. 3 illustrates the lowering of the van on to the steamboat deck.

For the purpose of facilitating the transport of coal, several South Lancashire collieries use coal waggons constructed with three detachable sections or boxes, in place of the usual waggon body. Each section carries on an average 2½ to 3 tons of coal, making a total carrying capacity of the sectional waggon 7½ to 9 tons, as against 9 to 10 tons of the ordinary coal truck. When it is required to discharge these trucks it is only necessary to lift any section desired by means of lifting rings provided, and empty through a bottom door or in the usual tip method adopted, with a third chain attached to one end for the purpose of tipping. The above arrangement enables the coal-handling machinery at any coal terminus, etc., to be of a much simpler and lighter character than would be required for dealing with the whole truck.

On the Donegal Railway Mr. R. H. Livesey, the general manager, has had to contend with the question of transit over two different

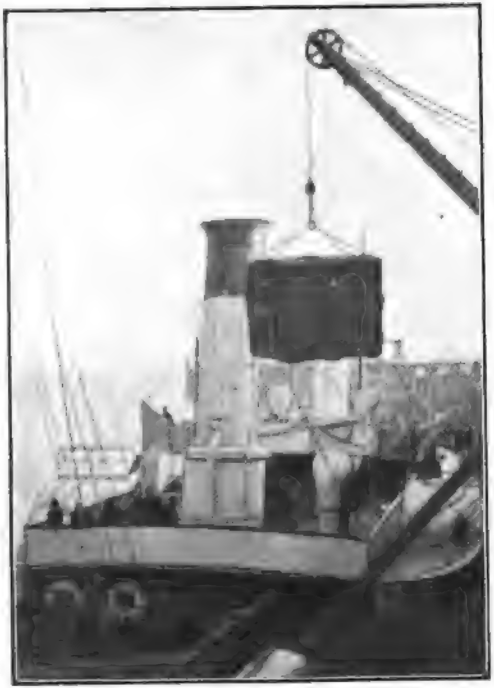


Fig. 3

Fig. 2.

gauges, viz., 5 ft. 3 in., which is the standard gauge of Ireland, and 3 ft., which is the gauge of the Donegal Railway. Figs. 4 to 7 illustrate the arrangement, and I cannot do better than describe the operation in Mr. Livesey's own words. He says :—" No lifting arrangements are required, as the bodies are taken over by means of rollers, which run on rails secured to the under-frames. The size of the bodies are the same as used by the broad gauge in this country —*i.e.*, 5 ft. 3 in.—and they are 15 ft. 6 in. long by 7 ft. wide. We carry any description of class of goods in them. The system was only brought into use about four years ago, and since then it has been such a success that we have decided to gradually alter the whole of our goods, etc., waggons to it, as it has done away with delays due to transhipments and loss through breakage, besides effecting a great saving in cost of handling, as two men can do all that is required in a few seconds.'

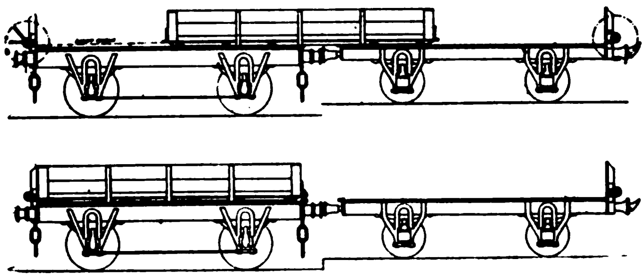


FIG. 4.

A somewhat similar arrangement is that of Cowan's patent truck, illustrated in Fig. 8. The object is the same in both cases, viz., to tranship goods in bulk without unloading.

From the information and illustrations which have just been given it is not difficult to suggest a system of dealing with goods on electric trolley lines or electric tramways which should prove adequate for all purposes, and which shall comply with the greater number of the conditions already set forth. I propose two forms of goods trucks, one on the lines of the Pittsburgh Express Car, Fig. 9, for conveying miscellaneous goods and for local traffic, but modified to meet conditions of English practice as shown in Fig. 10; the other to be an application of the principle adopted by the South Eastern Railway and the Lancashire Colliery Railways to which I have already referred, viz., detachable tops on plain trucks, provided with facilities for removal by means of cranes. This arrangement is indicated in Fig. 11, and should answer for the majority of cases. The comparative sizes of this car and the ordinary railway truck and road lurry are as follows :—

Electric trolley truck	...	22 ft. 0 in. × 6 ft. 6 in.
Railway truck	...	16 ft. 0 in. × 7 ft. 10 in.
Road lurry (two-horse)	...	17 ft. 6 in. × 7 ft. 3 in.

The train in this case would consist of one motor truck and one trailer, carrying together from 18 tons to 20 tons. The motor trucks would be of the double bogie type, with an extension at each end for the motor man and controlling gear.

Magnetic track brakes would have to be provided, in addition to electric and wheel brakes, for use on heavy gradients and for emergency. The trucks would also be provided with wooden or iron bars for supports for tarpaulin covers, when required.

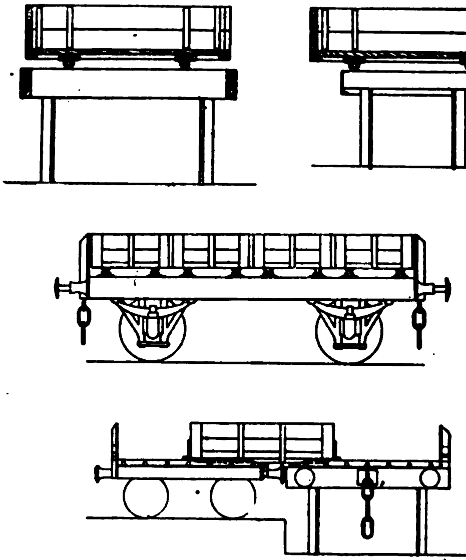


FIG. 5.

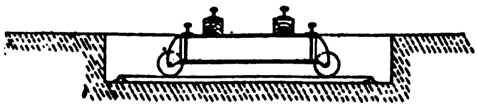
In the United States the conveyance of goods on electric trolley lines has been very considerably developed. The Pittsburg Express Company, Pittsburg, Pa., had, in 1900, in operation ten cars of the type shown in Fig. 9.* Each car will carry 8 tons, the length of the car being 29 ft. 10 in. overall. The Company in 1900 was making an average of sixteen round trips per day, with a total daily mileage of 270 car-miles, or 7,020 car-miles per month. It handles both express packages and heavy freight of all kinds. On level and through runs, when there is not too much local street delivery, express trailers can be

* See also *Street Railway Journal*, December issue, 1900, page 1,148. For further reference to freight and express conveyance see also the following issues of the *Street Railway Journal*:—June issue, 1897, Newburgh Street Railway Company, page 348; September issue, 1898, Buffalo and Lockport Railway Company, page 535; June issue, 1899, Mail Car, page 353; August issue, 1900, Funeral Cars, page 382; December issue, 1900, Funeral Cars page 703.

operated satisfactorily, even during the busy part of the street-car day, and for night runs their use is a great aid in reducing the cost of transport.

Some considerable development of goods traffic on electric trolley lines has taken place in Detroit, Michigan, notwithstanding a bye-law which prohibits the use of trailers, and which levies a tax of one dollar per car per round trip, regardless of whether the car is empty or loaded.

The illustrations Figs. 12 to 17 give a fair idea of the traffic handled. The main depôt is 45 ft. by 195 ft. On one side is the team track or driveway, where freight is received and delivered. On the east side of the shed there are double tracks with accommodation for four cars on



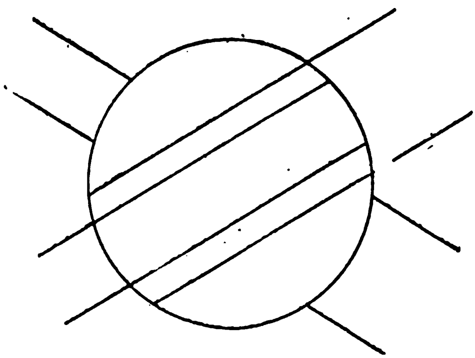


Fig. 6.

each track, with ample room for switching. The interior of the shed is clear of all posts, thus giving ample floor space necessary for prompt receiving and loading the freight. There is also cold storage for the protection of perishable goods during the summer months.

The carriage of goods in Detroit had its origin in the transportation of milk, which was originally handled in a small compartment on passenger cars reserved for baggage, but which has now grown to such proportions as to tax daily the capacity of entire special cars. The rate on the different commodities handled is according to the value, dimensions, and weight of each article. For example, shipments of glassware, furniture or suchlike are rated much higher than milk or hardware.

On the Continent we have to turn to Belgium—the land of agricultural produce—for any extensive system of light railways for goods traffic.* Most of these, however, are steam railways, and differ but slightly in their methods and operation from the ordinary main railroads of the country. As a matter of fact they act principally as affluents or feeders to the larger railways.

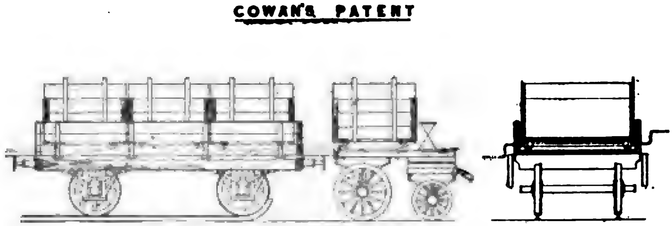


FIG. 8.

There is in Germany a freight line constructed by the Union Electricitäts Gesellschaft at Aachen (Aix-la-Chapelle) six years ago, which runs ordinary motor trucks, having, however, no special detachable body.

When the writer was visiting the Düsseldorf Exhibition in 1902, he saw a very interesting system of general goods and milk conveyance on electric tram lines. The line is really a light railway owned by the

* A correspondent in Brussels sends the following remarks:—"Since the 1880 Belgian law, ruling the working of light railways, more than 2,600 kilometres of 'Vicinal' tramways have been constructed (one metre gauge, with the exception of two lines), and they are all reported to be in a prosperous state. This latter point, although being rather difficult to ascertain (as the working of the lines have all been leased to private concerns), may be considered as correct, because the Société Nationale des chemins de fer Vicinaux, proprietors of all lines, consider the present result as satisfactory. All these tramways, with a few exceptions, are steam tramways, and there is a vague question of replacing steam by electricity; they are destined for the conveyance of goods, passengers and luggage. Light railways are here mostly affluents of transport to large railways, especially the farm and greenhouse products, such as beetroots, fruits, vegetables, milk, eggs and butter, also cattle and all market produce, for large centres such as Brussels, Ghent, Antwerp, Liège, etc. As regards mineral traffic, Belgium being small, and the system of the State railways very much developed indeed, collieries avail themselves of private sidings. The charges, freight, etc., are fixed by the Belgian State, through the Société Nationale des chemins de fer Vicinaux, and are determined according to the local necessities. As regards the revenues, they vary with local conditions, and the Société Nationale themselves fix the probable revenues the lines are to bring. As an average they allow from 1,700 francs to 3,000 francs per kilometre per annum to the concern working, under lease, the line; dividing the surplus with the latter in proportion to 30 per cent.-50 per cent. (for benefit, maintenance of the line, etc.), when their estimate has been confirmed by the receipts. Should the receipts not amount to the fixed allowance, the difference is borne by the Société Nationale. It is reported that, as a rule, the Société Nationale share the surplus after two to four years' working. About thirty private concerns find a remunerative business in working, under lease, the 'Vicinal' lines."

FIG. 7.

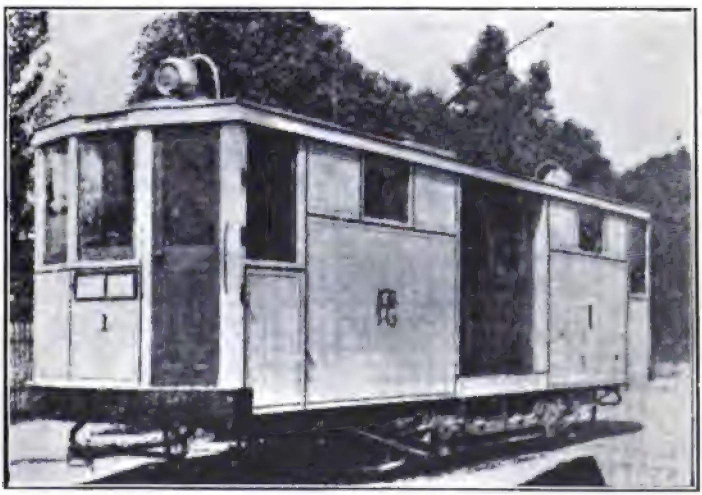


FIG. 9.

Rheinische Bahn-Gesellschaft, and carries passengers and goods. Unfortunately, no illustrations are available. The articles carried are piece-goods, milk and agricultural produce. The line is 22 kilometres in length, and connects the two towns of Düsseldorf and Krefeld, having an aggregate population of 350,000. The intervening country is principally agricultural, and there is a very considerable milk traffic from the intermediate stations to Düsseldorf. For the carriage of piece-goods the almost universally current rate (in Germany) of 20 pfennige per ton per kilometre is charged (equal to about 3⅐d. per ton per mile).

The carriage on milk is on the following basis: For a distance of 10 kilometres a minimum rate of 30 pfennige per 100 kilos. (equal to 1⅜d. per cwt.), and for every further five kilometres, 5 pfennige extra (about 3 miles—½d. extra).

Carriage is charged on, (*a*) the weight of the milk carried, including the weight of the cans; (*b*) half the weight of the returned empty cans. Fractions of 10 kilos. are charged as 10 kilos. full.

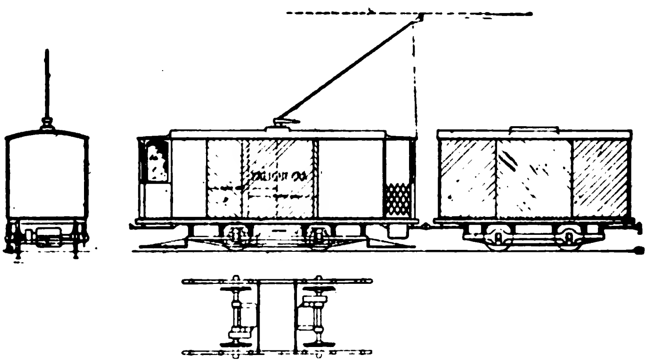


FIG. 10.

Milk is received and forwarded principally in the early hours of the morning to 7.30 a.m. An opportunity is, however, afforded to forward the milk also at noon and in the evening. Piece-goods are forwarded three times a day, viz., morning, noon, and evening, by permanently appointed passenger trains.

Goods are conveyed in 4-axled covered wagons of $8 \times 2 = 16$ square metres (175 square feet) floor space, having a tonnage of 10 tons.

A complete translation of the conditions for forwarding milk, etc. together with the tariff charged will be found in the Appendix.

In Switzerland there is a line between Burgdorf-Thun, which is built for passenger service, using ordinary motor trucks, and electric locomotives with freight trucks (without motors) for the freight service.

To revert to the United Kingdom, one finds very little that has been done in this direction even from a prospective standpoint. The Light

Railway Act of 1896 has been almost entirely inoperative. When the opportunity for carrying goods has arisen, such as in South Lancashire, in the Potteries district, on the Middlesbrough and Stockton lines and elsewhere, many difficulties have been placed in the way by the action of property owners and local authorities. This aspect I will deal with in the next section.

The South Lancashire Tramways Company have now appointed a goods traffic manager who will deal with the area in which they are interested. The Huddersfield Town Council have contracted with Messrs. Martin, Sons & Co. to convey coal for seven years over the tramways from a railway siding. The company requires from 45 to 50 tons of coal per day. Specially constructed waggons will be used; they will hold about 5 tons of coal each, and each will be driven by two electric motors. There is a short line from Welshpool to Llanfair for the conveyance of both goods and passengers. A company called the Tramways Parcel Express Syndicate, of Bradford, Yorks, exists for the collection and delivery of parcels, and it is open to make arrangements in connection with tramway undertakings for the conveyance of parcels

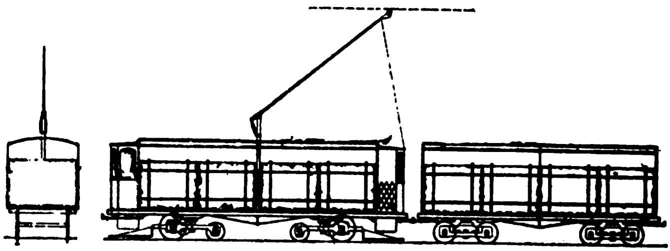


FIG. II.

at a mileage rate. The company provides its own crates and receptacles for parcels, and places them on and removes them from the cars, so that no delay or expense attaches to the tramway authorities. Special facilities would of course have to be provided for accommodating the crates, etc.

Messrs. Twinberrow and Sheffield, of Newcastle-on-Tyne, have designed several special types of goods waggons, both motor and trailer, suitable for running on tramway lines, for conveying coal, bricks, pig iron and general merchandise.

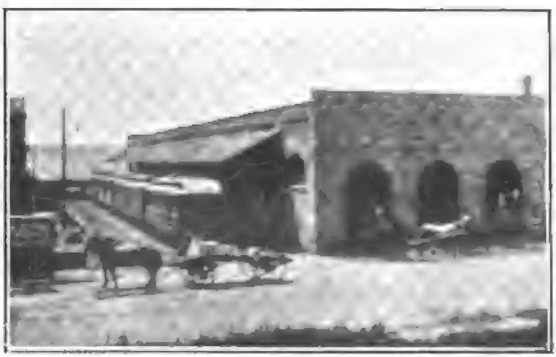
Direct and Indirect Advantages.

The principal advantage resulting from the development of goods traffic on tramways will, of course, accrue to the company or authority owning the tramways or over whose system the goods are conveyed.

Parliament has already granted the powers to convey such goods and although additional capital is required to provide the necessary

Interior View of Milk Car.

Interior View of Electric Depot at Detroit.



Tracks for Cars on East Side of Electric Depot at Detroit.

INTERIOR VIEW OF EXPRESS CAR.

TEAM TRACK DELIVERY ON WEST SIDE OF ELECTRIC DEPOT, DETROIT.

FREIGHT OFFICE AND MILK PLATFORM AT CLAWSON, MICH.

rolling stock and equipment, the earning capacity of the permanent way can by this means be very largely augmented. The cost of the permanent way is, in the majority of cases, the more expensive portion of the system, costing from £7,000 to £10,000 per mile.

The advantages to the manufacturer, colliery owner, and warehouseman are quick delivery and low freight charges.

The advantages to local authorities generally are more than are immediately apparent. For instance, in any manufacturing community where there are cheap freight rates combined with other local facilities, there the manufacturer will settle. Not only will the rateable value be increased, but the present rates will in all probability decrease. The profits accruing from municipally-owned electric traction undertakings are often applied to the relief of the rates, and in those cases where independent companies own and work them the roadways are not only greatly improved for general traffic but are also kept in repair. The principal public benefit in this connection, however, will consist in the great relief of the streets from lorry traffic. The cost of road maintenance from this cause alone is very great. The surveyor to the Tyldsley Urban District Council finds that the cost of road maintenance for four years averages £233 2s. per mile per annum, exclusive of scavenging. In Bolton the annual expenditure on main roads varies from £7,000 to £10,000, and on other roads about an equal amount. The surveyor is of opinion that if goods were carried on the tramways a considerable saving would be effected, and if this is the experience in these towns it may safely be assumed to be the case also in Liverpool, Manchester, etc.

In a paper read before the annual meeting of the Incorporated Association of Municipal and County Engineers, at Leicester, by Mr. W. Worby Beaumont, entitled "The Wear of Roads by Horse Haulage and Motor Traffic," the author remarks: "Since the days when Telford and MacNeill, his resident engineer (afterwards Sir John MacNeill), and others gave so much attention to the subject, it has been recognised that the wear of roads by horses' shoes was considerably greater than the wear of roads by the wheels the horses hauled. It was shown by the observations of MacNeill that the wear by the horses hauling heavy vehicles and heavy loads was less than that by the horses hauling the lighter loads at the higher speeds. The relative proportions of the wear under these different classes of traffic were fully stated in evidence before the select committee on steam carriages in 1831, and very little has transpired since to alter the qualitative value of the conclusions then announced, although road and vehicle improvements have added to the number of exceptions to their quantitative value." (See Report of Select Committee in Gordon's "Elemental Locomotion," page 131, *et seq.*) The causes of road wear were summarised for a general statement, and may be collated as shown in the following table :—

General Results of Observations of Causes of Road Wear and Deterioration.

Kind of Vehicle and Load.	Wear due to atmospheric causes.	Wear due to wheels.	Wear due to horses' feet.
London and Birmingham Coaches: Weight, 16 cwt. to 18 cwt. empty; loaded, 45 cwt.; speed, 8 to 12 miles per hour	20 per cent.	20 per cent.	60 per cent.
Wagons: Weight, 25 cwt.; loaded, 92 cwt.; speed, 3 miles per hour	20 „	35·5 „	44·5 „

Another of the indirect advantages will be the decreased cost of generation at the power-stations. It is well known that an increase in the output of a generating works, without a corresponding increase in the maximum demand or staff, results in a much lower average cost per kilowatt-hour or Board of Trade unit. In Table III. a graduated scale of costs is given for varying load-factors, from which the principle just

TABLE III.

Cost of generating electrical energy with varying load factor in pence per kilowatt-hour at dynamo terminals, maximum demand—2,000 K.W.

Items of Cost.	Electric Lighting. 10% load factor.	Combined Electric Lighting and Traction. 20% load factor.	Electric Traction, Passengers only. 40% load factor.	Electric Traction, Passengers and Goods. 60% load factor.
1. Coal at 12/- per ton, Oil Waste, Water and Stores	Pence ·53d.	Pence ·41d.	Pence ·38d.	Pence ·35d.
2. Wages of Engine Room and Boiler Room, Staff, &c., superintendence at 8 hour shifts ...	·30d.	·20d.	·12d.	·08d.
3. Repairs and Maintenance	·25d.	·14d.	·07d.	·05d.
4. Depreciation at 5 per cent. minimum per annum ...	·17d.	·10d.	·06d.	·03d.
Total works cost ...	1·25d.	·85d.	·63d.	·51d.

enunciated will be apparent. The saving between a 60 per cent. load-factor and a 40 per cent. load-factor is nearly 20 per cent.; or in other

words, more than 20 per cent. more energy can be generated at the higher load-factor at the same cost. In many cases this will, of course, represent an increased revenue of many thousands of pounds per annum on the generating portion alone.

Disadvantages and Difficulties.

It is not my intention in this paper to critically examine many of the so-called disadvantages (as distinct from engineering and traffic difficulties) which have been urged as almost insurmountable obstacles to the carriage of goods on electric tramways. It is possible that they may be referred to in the discussion hereon, and I will then endeavour to reply to such points as may be raised. The most important drawback, however, has been stated to be the noise that would be created during the night by transporting heavy goods on rails through suburbs, thereby causing an almost intolerable nuisance to residents along the line of route. In my opinion this objection is very largely a matter of the imagination, to which undue importance has been attached. The lines of route which will be affected already form and are used as the highways for goods traffic during the night, and such highways which run out of, or through any town of importance, are paved with granite or grit setts. The disturbing and irritating noise thus caused by horse-drawn lorries is very considerable, and I think is far more accentuated than would be the case if all goods were conveyed on rails. Instead, therefore, of adding any additional disturbance in this respect, the conveyance on the tram rails would tend to mitigate an existing nuisance.

On the other hand there are undoubtedly many engineering and traffic difficulties to be surmounted. The principal of these may be stated to be as follows :—

1. The method of distributing goods to outlying districts, mills, warehouses, etc.
2. The difficulty of obtaining the sanction and approval of the local authority, property owners and frontagers to the laying of additional lines and sidings.
3. The arrangement of speed on both single and double lines of track, so as not to impede the ordinary passenger-car service.
4. The inauguration of the system.

With regard to the first of these problems, it will no doubt be profitable in many instances to lay down special lines and sidings, but in others some alternative method will have to be adopted. Even if the horse-drawn lurry cannot be dispensed with, the cost of transference in bulk from the electric truck to the lurry will be far less than unloading trucks in railway sidings. It will, of course, be necessary to provide depôts in each town for dealing with goods for isolated districts and local traffic. Such depôts would have to be provided with cranes, but there would be almost an entire absence of loose goods spreading about the floor area, which is so characteristic of railway goods sheds. Indeed, these depôts could be comparatively small, as the traffic would be

quick, exchanges rapidly effected, and the necessity for storage reduced to a minimum. Steam-propelled road lorries might replace horses in order to reach isolated places, but the use of such rolling stock would be entirely auxiliary, employed only for distribution in bulk. In cases where it is comparatively easy to obtain wayleaves for poles and line supports, such as in agricultural districts, it will be possible to form an efficient connection with collieries and mills by means of aerial ropeways. These can now be made to take any curvature, and Mr. J. Walwyn White, of Widnes, who has made this subject a special study, states that the cost of a complete equipment, including power, may be taken at £1,000 per mile.

A very real and immediate difficulty is found in obtaining the sanction to lay additional lines and sidings. It affects both municipal and private enterprise alike, although, of course, the private enterprise is in much the worse position. Whether powers have been obtained under the Tramways Act or Light Railways Act, the whole course of the original procedure of applying for powers has to be repeated for every additional line required. It is true that the Board of Trade can exercise very limited powers in this respect, but after a concession has been obtained in the usual way, it should not be allowed to remain practically impossible to obtain such reasonable and beneficial extensions as special short lines to mills and sidings from the pre-determined track. Under the existing legislation, therefore, it is possible for a local authority or private individual to withhold in the most arbitrary manner the consent which is necessary to lay even a special siding into a works. This appears to me to be the most important condition to be remedied, and comprises the key to many of the other difficulties. I commend the earnest consideration of this matter to the Tramways and Light Railways Association, as a subject of real practical utility and urgency.

The arrangement of speed for goods traffic on both single and double lines of track, so as not to impede the progress of the passenger cars, is a matter of importance. Passengers cars have to be run at a high rate of speed, and it is obvious that in many cases it would be neither convenient nor economical to convey goods trucks at the same rate. It will, therefore, probably be found more convenient to convey very heavy goods principally during the night time, but for loads of not more than five tons per truck, no inconvenience to passenger traffic should occur. It must be remembered that passenger cars, although running at a high rate of speed, make frequent stops, and that in consequence the average rate will be not greater than that attained by a goods car. When, however, the traffic in goods becomes of considerable magnitude, it will pay to lay special sidings.

I have catalogued as one of the difficulties, the actual inauguration of the system, and it might well be considered a hopeless prospect if a complete solution of every detail were necessary before a commencement could be made. As a matter of fact, although I have dealt with many aspects, no such complete solution is required. Each case will present phases of purely local interest, and therefore in starting such a system I advise small beginnings. Many of the problems will thus solve themselves. We can start with fairly well standardised conditions

as regards track and overhead equipment. Interchange of traffic and through running in connection with contiguous undertakings will in nearly every case be a necessity, and the arrangements should follow the lead of the railway companies. Prior to any such necessity, however, it will probably be found advisable to make a commencement with local requirements. In many undertakings there exist large mills and factories providing cartage for hundreds of tons of goods weekly, and in some single instances as much as from 300 to 500 tons per week. Some of the collieries in the South Lancashire area have an output of from 500 tons to 1,000 tons per week for local use only, such as supplies to mills, gasworks, etc., and for which the usual cartage charge is 10d. per ton per mile. In such cases the railway is of no use whatever.

Conclusion.

In bringing this paper to a conclusion, I express the hope that the information which I have collected, and the discussion upon the points which I have raised, will be productive of some immediate experiments in connection with carriage of goods on tramways. I ask for the co-operation of the general manufacturing community, especially in an endeavour to obtain greater facilities from Parliament in extending existing systems for this purpose. A committee has recently been formed entitled the "Lancashire Transport of Merchandise Committee," having for its object the furtherance of a general scheme of goods conveyance on Electric Tramways in South Lancashire. The offices are in the Municipal Buildings, Liverpool, and among the members are the following gentlemen :—

Lancashire Transport of Merchandise Committee.

Sir John A. Willox	Liverpool.
Alderman Charles Petrie	Liverpool.
Alderman Frederick Smith	Liverpool.
Councillor Edward Lewis Lloyd	Liverpool.
Dr. Sephton, Manor House, Atherton	Atherton.
Mr. Borron, The Heights, Golborne, near Newton-le-Willows	Haydock.
Alderman T. E. Smith, Dun Withins, Heaton, Bolton ...	Bolton.
Alderman J. C. Gamble, Haresfinch, St. Helens	St. Helens.
Joseph Berry, Albion House, Swinton, Manchester ...	Swinton.
Thomas Dennett, Derby Street, Prescot	Prescot.
William Sharrock, Harvey House, Gathurst, near Wigan...	Pemberton.
David Dove, Dove Leigh, Hall Lane, Hindley	Hindley.
Alderman T. R. Greenough, Beechwood, Leigh	Leigh.
T. H. Thomas, Mersey View House, Halebank, Widnes...	Whiston.
Thomas Macleod Percy, Cinnamon House, Ince, near Wigan	Ince.
W. B. Richardson, Sunny Bank, Bolton Road, Farnworth, R.S.O.	Farnworth.
William Valiant, Gerard Street, Ashton-in-Makerfield.	

Alderman H. Chadwick, Crossbank House, Manchester Street, Oldham.
W. J. Tomlinson, 6, Church Street, Darwen.
H. E. Clare, Lancashire County Council, Preston.
Mr. A. S. Giles, Manager of Tramways, Blackburn.
A. E. Johnson, Bickershaw Hall, near Wigan ... ... Abram.
Geo. H. Cox
Charles Lancaster } Chamber of Commerce.
Colonel James Goffey
John Robinson, The Grange, Haydock, St. Helens ... Golborne.
Alderman J. W. Wareing, Bedford House, Widnes ... Widnes.

It will be apparent from this very representative committee, that the interest in the scheme does not centre in any one undertaking or portion; on the contrary, each undertaking has interest in common with the others, and the extension or development of the traffic on any portion must beneficially affect the remainder.

As a final word, I also take this opportunity of expressing the opinion that it would be to the advantage of the railway companies to co-operate with the tramway undertakings. Although at first sight the proposals described herein may appear entirely antagonistic to and competitive with the railways, yet in reality this scheme may be of great advantage to them. It will obviously affect the short-distance goods traffic on railways, but while taking away with one hand it may give twofold with the other. The tramlines would act as important feeders to the railways, bringing goods and produce to such centres and with such dispatch for conveyance for long distances. Something in this direction has already been accomplished on behalf of passenger traffic.

The South Lancashire Tramways Company have arranged with the Great Central Railway Company to book passengers and parcels through by their electric cars from Leigh to St. Helens, Wigan, Manchester, etc. The traffic will be conveyed by car to Lowton St. Mary's, thence by Great Central trains. Such co-operation between a tramway and a railway company is somewhat new in this country, but another example is that brought about by the recent arrangement between the London United Tramways and the Underground Electric Railways Company of London. In the latter case, however, to a large extent the capital of the tramway company is held by the railway company. In both cases the results to the public and the shareholders ought to be very satisfactory.

APPENDIX.

RHEINISCHE RAILWAY COMPANY, DÜSSELDORF.

GOODS TARIFF BY THE LIGHT RAILWAY.

CONDITIONS FOR FORWARDING.

The receiving and forwarding of small freights is subject to the following regulations, and to the fixed tariff as set forth herewith, and also to the conditions laid down by the State Railways. It is further subject to the regulations laid down in the "Traffic Orders for the German Railways," the "German Railways Goods Traffic, Part I.," the "Tariff Regulations and Classification of Goods," and the "extra tariffs," as far as they refer to small goods-carrying.

The following will not be forwarded :—

(*a*) Corpses and animals.
(*b*) Articles over 8 metres in length.
(*c*) Those articles enumerated in Part "B" of "Traffic Orders for the German Railways" (inflammable and explosive articles).
(*d*) Such objects which present more than ordinary difficulty in dealing with.

The times of the trains for each stopping-place are specially placarded up.

On Sundays and public holidays there will be no goods traffic. On such days milk only will be forwarded.

Days are considered in general as holidays where the local authorities allow the men working in public places the day off.

The drawing up of a freight bill can be made similar to the form used on the State Railways.

Principles upon which the Freight is Reckoned.

The freight is calculated in kgs. Goods under 20 kg. in weight count as 20 kg., and each fraction above 20 kg. shall count as 20 kg.

The freight will always be charged up to 5 pfg., and over this will be charged as 10 pfg.

There are two different freight tariffs, according to whether the goods come under the heading "small freight" or "market goods."

Under "market goods" are understood to be those which are produced from the cultivation of the land, and are being sent to the market. (All description of vegetables, fruit, potatoes, etc.)

The smallest charge for forwarding is 40 pfg.

Small freight will be forwarded in accordance with the tariff for same, the smallest charge being 30 pfg.

Light but very bulky goods will be charged 50 per cent. extra, and must consist only of those enumerated in the "German Railway Goods Tariff." The smallet weight will be reckoned to 30 kg.

TARIFF FOR THE FORWARDING OF SMALL FREIGHT GOODS.

Freight per 100 *kg.*

From and to	Krefeld.		Fischeln.		Osterath Hoterheide.		Forsthans Meer.		Büderich.		Oberkassel.		Düsseldorf.	
	General small freight.	Reduced-rate small freight.	General small freight.	Reduced-rate small freight.	General small freight.	Reduced-rate small freight.	General small freight.	Reduced-rate small freight.	General small freight.	Reduced-rate small freight.	General small freight.	Reduced-rate small freight.	General small freight.	Reduced-rate small freight.
	m. pf	m. pf.	m. pf.	m. pf.	m. pf.	m. pf.	m. pf.	m. pf.	m. pf.	m pf.	m. pf.	m. pf.	m. pf.	m. pf.
Düsseldorf ...	— 44	— 36	— 40	— 33	— 33	— 28	— 27	— 24	— 24	— 21	— 18	— 16	— —	— —
Oberkassel ...	— 39	— 32	— 34	— 29	— 28	— 24	— 21	— 18	— 19	— 17	— —	— —	— 18	— 16
Büderich ...	— 32	— 27	— 28	— 24	— 21	— 18	— 16	— 14	— —	— —	— 19	— 17	— 24	— 21
Forsthans Meer	— 29	— 25	— 25	— 22	— 19	— 17	— —	— —	— 16	— 14	— 21	— 18	— 27	— 24
Hoterheide ...	— 23	— 21	— 19	— 17	— —	— —	— 19	— 17	— 21	— 18	— 28	— 24	— 33	— 28
Fischeln ...	— 17	— 15	— —	— —	— 19	— 17	— 25	— 22	— 28	— 24	— 34	— 29	— 40	— 33
Krefeld ...	— —	— —	— 17	— 15	— 23	— 21	— 29	— 25	— 32	— 27	— 39	— 32	— 44	— 36

The following articles will come under a reduced rate :—

(1) Wood, and wooden articles of all sorts.
(2) Metals, and metal wares.
(3) Iron, steel, iron and steel wares.
(4) Scrap metal.

When larger weights are to be forwarded, the following reductions are allowed :—

On weights from	3,001–3,500 kg.	a reduction of	10%	of the freight.
Do.	3,501–4,000 kg.	do.	15%	
Do.	4,001–4,500 kg.	do.	25%	
Do.	4,501–5,000 kg.	do.	40%	

Exceptional Tariff.

Comes into force for those goods which arrive at Düsseldorf by water, and are immediately delivered on to the Light Railway—also *vice versâ*.

Freight per 100 *kg.*

From	Krefeld.	Fischeln.	Osterath.	Hans Meer.	Büderich.	Oberkassel.
	20·1 km.	17·3 km.	13·3 km.	9·3 km.	7·3 km.	3·3 km.
Düsseldorf	26	24	20	16	14	11

Tariff for Forwarding of Market Goods.

Per 100 *kg. Weight.*

From and To.	Heerdt Lorick.	Büderich.	Forsthans Meer.	Oberath Bovert.	Osterath Hoterheide.	Fischeln.	Krefeld.
	pf.	pf.	pf.	pf.	pf.	pf.	pf.
Düsseldorf	30	35	40	45	50	60	70
Krefeld ...	—	30	45	40	35	20	—

Basis of Calculation of the Freight.

	Per Kilometre and 100 kg.
From Lorick to Düsseldorf	5·5 pf.
„ Büderich	5·0 „
„ Forsthans, Bovert, Hoterheide...	4·0 „
„ Fischeln and Krefeld	3·5 „
„ Büderich and Forsthans Meer to Krefeld ...	4·5 „
„ Bovert, Hoterheide, and Fischeln, to Krefeld	5·5 „

LIGHT RAILWAY, FORSTHANS MEER—UERDINGEN.

I. Direct Traffic. Tariff for Freight Goods.

Freight per 100 kg. Lowest Possible Charge, 30 pf.

From and To	To and From							
	Strümp.		Latum-lank		Stratum.		Uerdingen.	
	General.	Reduced rate.	General.	Reduced rate.	General.	Reduced rate.	General.	Reduced rate.
	m. pf.	m. pf.	m. pf.	m. pf.	m. pf.	m. pf.	m. pf.	m. pf.
Düsseldorf ...	— 32	— 27	— 36	— 31	— 41	— 35	— 47	— 39
Oberkassel ...	— 27	— 22	— 31	— 26	— 36	— 30	— 42	— 34
Büderich	— 21	— 17	— 25	— 23	— 30	— 25	— 36	— 29
Hans Meer ...	— 17	— 15	— 21	— 19	— 26	— 23	— 32	— 27
Osterath	— 24	— 20	— 28	— 24	— 33	— 28	— 39	— 32
Fischeln	— 30	— 25	— 34	— 29	— 39	— 33	— 45	— 37
Krefeld	— 34	— 28	— 38	— 32	— 43	— 36	— 49	— 40

II. Local Traffic.

Freight per 100 kg. Smallest Charge for Forwarding, 30 pf.

Strümp	— —	— —	— 17	— 15	— 22	— 19	— 27	— 23
Latum-lank ...	— 17	— 15	— —	— —	— 18	— 16	— 22	— 20
Stratum	— 22	— 19	— 18	— 16	— —	— —	— 18	— 16
Uerdingen ...	— 27	— 23	— 22	— 20	— 18	— 16	— —	— —

Market Goods.

Freight per 100 kg. Smallest Charge for Forwarding, 40 pf.

	From and To			
To and From	Strümp.	Latum-Lank.	Stratum.	Uerdingen.
	m. pf.	m. pf.	m. pf.	m. pf.
Düsseldorf	— 40	— 45	— 50	— 60
Krefeld ...	— 45	— 50	— 60	— —

Rheinische Railway Company,
Light Railway—Düsseldorf-Krefeld. *Form I.*

Conditions to be Observed for the Regular Forwarding of Milk.

1. *Arrangement of Requirements.*

Arrangements for the regular forwarding of milk from one station to another, together with the returning of empty milk-cans by special trains, can be made monthly, as long as the delivery takes place daily and the amount of milk carried during the course of the month comes to at least 500 litres, or the freight for this quantity be paid for. This does not hold good for those who begin forwarding after the month has once started. The forwarding arrangements can commence or finish on any day.

2. *Senders' Notification.*

Persons desirous of making arrangements for forwarding must, after first becoming acquainted with the regulations, hand in particulars of the nearest stopping-place, at least three days before they wish the forwarding to take place. There is no charge made for this.

3. *Security, Fines, Payments.*

The consignor must deposit a sum equal to one and a half times the monthly freight account as a security for payment of freight. Interest on this amount will not be allowed by the management, but this sum will be returned at the end of the month after the first account has been paid. Should the freight reach or overstep the amount provided for by the security (in the course of a month), then the consignor must pay the corresponding amount upon being called upon to do so by the station official, otherwise further deliveries will not be executed.

4. *Descriptions and Markings of the Vessels.*

Vessels to be used for forwarding milk must be portable, and possess a tight cover, so that the milk cannot flow out even if the cans fall over.

The capacity of a vessel shall not exceed 40 litres, and must be plainly written upon it, together with the weight of the vessel. An official calibration or testing of capacity must not be necessary on the part of the railway company.

Each vessel which is intended for milk transport must have a massive brass label, engraved distinctly (that it may be easily read by artificial illumination), giving the name of the consignee and the receiving station, as well as the name of the consignor and sending station. The labels are to be removed by the consignor if at any time they should become illegible. If milk should be transported in small containing vessels (for instance, glass bottles) and placed in boxes or cases, each case must be filled up and must not weigh more than 40 kg. They must be strongly constructed, and have on each side secure handles for lifting. On the cover of each case must be distinctly written, on one side the greatest weight of box filled up completely, on the other the weight of same with empty bottles. Before entering into the contract the box or cases must be sent to the station (stopping-place) in order to prove that the weights as given are correct; further, each case must be labelled with the consignee's name and station, as well as the consignor's name and station.

Vessels or cases of milk which do not correspond to the foregoing regulations will not be accepted.

In order to easily recognise the home station for the empty milk-cans it would be advantageous for each stopping-place to have a special colour, the colour to be painted on the covers of the cans.

Milk senders are therefore requested in their own interests to arrange this, so that each stopping-place may be thus recognised, and there will be little chance of cans going astray.

5. *Delivery Note.*

The consignor has to deliver up daily at the time that he delivers the milk to the sending-off station a written statement (milk delivery note) in duplicate, in which is stated—

1. How many vessels he is sending.
2. How many litres of milk the vessels contain.
3. What is the weight of the cans.

The milk delivery note must be procured by the consignor himself, or may be purchased at the stopping station. Bills of freight are unnecessary, as the milk delivery note takes its place.

6. *Incorrect Particulars of Weight.*

Should the quantity of milk be more than is stated on the milk delivery note, the consignor will be fined, besides the amount short, four times the total amount of the freight sent by that train.

7.

The loading and unloading of the milk vessels at the stopping-places is done by the sender and receiver respectively, under the supervision of the light railway official.

8. *Delivery to more than one Consignee.*

One consignor may deliver milk vessels to a number of consignees. In this case, the consignor must make arrangements with a representative at the receiving station so that he receives the whole consignment. Otherwise he must send on as many notes as there are consignees.

9. *Time of Delivery and Collection.*

Carts for the collection of full cans must not arrive at the stopping-places earlier than a quarter of an hour before the train arrives by which he is sending his consignment.

Empty cans likewise may not be brought to the stopping-place earlier than a quarter of an hour before the train is due in by which he intends returning the cans.

The return of the empty vessels takes place without any accompanying papers, solely by the marking on the cans.

10. *Calculation of Freight.*

For this calculation there is necessary—

(*a*) The weight of the forwarded milk, including weight of cans.

(*b*) Half the weight of the returned cans.

Every consignment will be entered up daily, particulars as to quantity and weight being taken from the milk delivery note. All accounts for milk delivery will be made up to the last day of the month, the freight being reckoned for the total quantity delivered, which must come to at least 500 kg. By regulating the weight of milk, one litre is assumed to be equal to one kg. weight. Further fractions of 10 kg. are reckoned as 10 kg. Accounts are made up to 10 pfg. amounts less than 5 pfg. counting as nothing, and amounts exceeding 5 pfg. as 10 pfg.

11.

Accounts are received by the consignors on the first day of every month. Payments must be made within three days at the latest. Should the consignor be behind in his payment, then no further milk will be accepted for forwarding.

THE COMMITTEE.

Düsseldorf. *The Rheinische Railway Company.*

I agree to the foregoing regulations, and enclose herewith copy of my requirements. day of , 190 .

....

DISCUSSION.

Mr. H. A. EARLE (*Chairman*), in opening the discussion, said that the difficulties in the distribution of the goods had not been fully stated by the author, although, no doubt, Mr. Gibbings knew of their importance. If the method of "house-to-house" delivery were attempted the rate of transit would be very slow, and passenger traffic would be Mr. Earle.

Mr. Earle. seriously impeded. A possible solution might be found in the establishment of large distribution centres. An important feature of any scheme should be co-operation with the great railway companies in the carriage of through traffic over great distances. The table referring to the Trade of Liverpool needed the qualification that the railway companies and other carriers did not necessarily handle the goods immediately, for a very great quantity found its way into warehouses, and remained there for varying lengths of time. He asked for information concerning the costs of transport, particularly the economies that were to be expected upon deliveries within distances say of thirty miles; also what were the inducements held out to investors in such undertakings. Another point was the maximum load to be anticipated per car. On railways three tons appeared to be a maximum, and yet the author stated in his 11th condition that the maximum should not be less than nine tons. How did he propose to raise the maximum to this figure?

Mr. Hill. Mr. G. HILL said that the results anticipated would be deferred for many years, owing to the delay arising out of the jealousies of the several local authorities, whose powers of obstruction under existing circumstances were incalculable.

Mr. Sheffield. Mr. T. W. SHEFFIELD, after referring to the question of vibration, alluded to the success attending the Detroit system, in large measure due to the absence of restrictive bye-laws and other regulations so generally imposed upon all such undertakings in this country. The maximum load proposed by his brother's firm—Messrs. Sheffield and Twinberrow—for tram vehicles was 15 tons.

Mr. Day. Mr. DAY asked if Mr. Gibbings had any scheme to adjust the terms for the interchange of through traffic between districts thinly populated and densely populated centres. This was a matter now under consideration, and affected the question of development very acutely. He should be glad of any assistance in its settlement.

Mr. Lindley. Mr. LINDLEY referred to the debate on the economies attending the use of large wagons, and considered that the decision of the L. & N. W. R. directors was scarcely fair. If the difficulties of collection and distribution were so great, and the resulting average weight so small, it seemed to point to the necessity for the assistance of auxiliary companies in the work of collection and distribution. Examples of such assistance could be found in the work done by such firms as Messrs. Sutton, Messrs. Pickford & Co., etc.

Mr. Twinberrow. Mr. TWINBERROW remarked that engineers are generally compelled by surrounding circumstances to adopt a solution of their difficulties which they know is not technically the best. In this country the "vested interests" that have to be respected, and the inordinate powers of obstruction that individuals possess were the cause of much bad engineering. He then discussed the present methods of handling coal, and concluded that the existing methods would disappear.

Mr. Wells. Mr. G. J. WELLS thought that much might be learnt from a consideration of the existing mismanagement of the great railway companies, and insisted upon the importance of dealing systematically with the arrangements necessary to cultivate traffic. After giving an example

of how a growing trade was killed by the simple expedient of altering the running of two trains so that a previous connection between a rural district and London ceased, he suggested that traffic managers should have as assistants men who knew the wants of traders and so could prepare the way for the development of new business, instead of so operating that any such growth was impossible. He thought that the circumstance of finding the S. E. R. being quoted as an example of rapid handling of goods was worthy of more than passing note. If he had not actually seen the method in use, he should certainly have queried the author's veracity on that point. The next speaker asked for information concerning the relative costs of carriage by motor-wagons, horse-drawn lurries and tram-vehicles.

Mr. F. SELLS asked if Mr. Gibbings had any information to give concerning the probable increase in maintenance charges. The carrying of goods can only pay if carried out on a large scale. It is then inevitable that traffic should proceed constantly—passenger by day, and goods by night—and he would therefore like to know how and when the necessary repairs to both the permanent way and the overhead equipment would be carried out. Mr. Sells.

Mr. A. H. GIBBINGS stated, in reply, that it would not be possible to arrange for a house-to-house delivery in connection with heavy goods traffic as suggested by the Chairman, nor would the necessity arise. He pointed out in his paper that depôts would have to be established in the various districts, but that in those cases where it was possible to run special sidings into mills, warehouses, etc., much economy in time and labour would be effected. The Chairman was wrong in assuming that three tons per truck was the maximum carried on railways, that figure being the average weight per truck. The difficulty which Mr. G. Hill experienced should be met by some further special legislation in order to prevent local authorities from exercising an absolute veto. Mr. Gibbings.

Mr. Gibbings mentioned several cases of tram-lines where the gauge was less than the standard and which were being operated electrically. On the subject of terms of agreement between the various authorities, the only suggestion he had to offer was to follow the example of the railway companies which appeared to satisfy the several authorities concerned. He next defended the methods suggested in his paper for handling goods in bulk, as being the most economical way. Mr. Sell's query he would answer in the future when the necessary data had accumulated. He felt that the several other difficulties that speakers had suggested would be capable of solution as they arose. If everything had to be solved before an undertaking was initiated, he ventured to think that the rate of progress would be even less than it was.

BIRMINGHAM LOCAL SECTION.

NOTES ON MOTOR-STARTING SWITCHES.

By A. H. BATE, Associate Member.

(Paper read at Meeting of Section, April 29th, 1903.)

INTRODUCTION.

In view of the growing importance of electric motive power, it is surprising that the accessories of the electric motor have so seldom been brought forward for discussion before the engineering societies. Whatever may be the reason, it certainly is not because such apparatus has reached a state of perfection; indeed, the wide divergence of designs would suggest that the subject is still in the quasi-experimental stage. The motor itself has become a fairly constant quantity, and a dozen machines by as many makers will show more points of similarity than of contrast.

The motor starter is at best a necessary evil. It is distinctly a drawback to have to spend one-tenth or more of the price of the motor for an apparatus to start it, and this may increase to a quarter or even to as much as half the cost if we wish to use the starting resistances for obtaining a variable speed. There is a very natural tendency to sacrifice good workmanship to cheapness in a part of the plant that is only in use for half a minute three or four times a day, and this no doubt accounts for the fact that cheaper work, both in the resistances and in the switch itself, is used for motor starters and controllers than would be accepted for any other purposes. On the Continent and in America more attention has been paid to this subject than has been the case in this country. Most of the improvements that have been made from time to time have come to us from abroad, but unfortunately these ideas have been embodied in switches of such a flimsy description that every one must have felt the incongruity of using them in conjunction with the solidly built motors that we make in this country. Until recently few English manufacturers have laid down standard lines of starters. For the most part they have been content to manufacture one by one and in small quantities as ordered, and under these circumstances have naturally fallen behind their foreign competitors, who have specialised in this class of work and have manufactured in quantities. Motor starters have to meet so many varied conditions that it is not easy in any case to combine all the requirements in a few patterns, and in this country the difficulty has been accentuated by the rules of the insurance offices and the very stringent and sometimes impossible regulations made by the engineers of the public supply companies. For instance, it is stipulated in some towns that the current shall not exceed five amperes on the first contact, with five-ampere steps up to full current. In other

places ten amperes are allowed, and in others fifteen amperes. In addition to this, some engineers require the switchwork to be protected by an iron case, others require a double-pole switch to be interlocked with the starting lever, or perhaps a slow motion has to be provided to prevent the current from being turned on too rapidly. All these conditions are unnecessary for the proper working of the motor, and it is not surprising that manufacturers have waited for things to settle down a little before committing themselves, since any design of switch that embodied all the requirements of all the public authorities would be too complicated to work and much too expensive to sell.

Next to the commutator of the motor, the starting switch is generally the part of the plant that gives most trouble, and this is due more often to the lack of a clear understanding between the maker and the installer as to what are the actual conditions of use than to any inherent defects in the design or construction. For example, one finds starters with resistances wound on asbestos tubes exposed to the weather; resistances embedded in sand or cement with switchwork of the lightest description used where starting and stopping is of frequent occurrence; or, to take an example of over-precaution, a switch with a costly slow-starting mechanism completely protected by a cast-iron case and installed in a dynamo-room. In no part of their specifications are some of our consulting engineers so indefinite as in the clause relating to the starters. After a detailed specification for the motor itself, one comes to a brief phrase about a suitable starter, without any indication of the conditions that settle which of the many available types will best meet the case. The object of this paper is to compare a few of the many forms of starting rheostats that are being made, and to outline the principles involved, in the hope of raising a discussion on the subject that may help to guide us in a choice of the best apparatus for use in the various conditions that have to be met.

Rating of Resistances.

There are three types of resistance in use, and for convenience we may name them :—(1) The *radiation* type, in which the resistance spirals are exposed to the air and the heat is dissipated by radiation and convection; (2) the *absorption* type, in which the wires are embedded in sand or cement and the heat is quickly absorbed by the sand and conducted away slowly; and (3) liquid resistances, in which the heat is absorbed by the electrolyte itself. In considering resistances in relation to heating, we may compare the conditions to those of a hoist motor. There is heavy duty for a short time, followed by a longer or shorter period for cooling down again. The German Institution of Electrical Engineers has recently framed a set of rules for the rating of motors which, I believe, is being pretty generally adopted on the Continent. They divide motors into three classes, according to the nature of the load for which they are intended. Thus, motors for *intermittent* work must give the full marked horse-power for one hour; and those for *continuous* use, for ten hours without overheating. There is a third class of rating provided, intermediate

between these two, for what is called *short time* use, in which the motor may be run at full load for two or three hours, or more, as the case may be, followed by a period of rest. In each case the class of rating and the time at full load must be marked on the output plate. The advantage of such a definite system of rating and labelling motors will be obvious to every one, and particularly to those who have to meet the customer who thinks he is being defrauded because a seven-horse-power motor for driving his shafting costs more than a ten horse-power motor for the crane. The question of the rating of motors does not come within the scope of this paper, but the matter has been mentioned because a similar classification may with advantage be applied to motor starters. Thus we get :—

Class 1. *Occasional use*, where a sufficient interval is allowed between the times of use to permit the resistances to cool down to air temperature. This represents the majority of cases, and in the writer's opinion the resistance should be able to carry the full-load current safely for at least half a minute, and carry an overload of 20 per cent. of current—that is, 50 per cent. of watts—for, say, ten seconds.

Class 2. *Frequent use*, where the interval is not sufficient to allow of complete cooling, or where the time taken in attaining full speed is unusually prolonged for any reason. The time for which the resistances would carry full-load current without overheating would be stated on the name-plate.

Class 3. *Continuous use* would include speed regulators.

Wire Resistances.

For the first class of work—that is, for occasional use—the absorption type of resistance is not only the cheapest but also the best. It has the disadvantage of being, perhaps, more difficult to repair than some other forms, and this is especially the case when cement is used to cover the wires instead of sand, but this slight drawback is more than compensated by the security that is gained by the cast-iron case protecting the wires from mechanical injury and from damp. Unfortunately this type of resistance is viewed with a certain amount of suspicion by many engineers. The resistances being out of sight, the work is sometimes very slipshod. For instance, iron nails fitted in holes in the slate base are used to support the wire spirals, and though they may be sufficient for the purpose, it is not a method of construction that is calculated to inspire confidence among men accustomed to engineering work. When properly rated, the absorption type will stand overloads for a short time just as well as the radiation type of resistance. When the wires burn out it is generally because they have been cut too fine for the work, or because they are being used for a class of duty to which they are not suited. When the operation of starting is repeated at short intervals the sand or cement does not have an opportunity to dissipate the heat, and sooner or later the wires get burnt. When the wires are exposed to the air it is possible to tell by inspection whether they are being overheated, but with absorption resistances one has to trust blindly in the maker's statement. In order

to inspire confidence and to insure against overrating a recognised method of testing such apparatus is very desirable. The writer would be satisfied with a starter that would pass the following test:—

A current 20 per cent. in excess of full-load current to be passed for a time depending on the size of the motor, the operation to be repeated at intervals of twenty minutes with full-load current without burning the surface of the wires, the time of passing the current being fifteen seconds for motors up to one horse-power, thirty seconds for motors up to two horse-power, and one minute for larger powers.

Liquid Resistances.

For use in exposed situations and for large powers a starter with a liquid resistance has many advantages, and if proper care is given to the design it will give less trouble on the whole than a wire-wound resistance. It is true that in the types with liquid held in an open box it evaporates and needs replenishing from time to time, but this small amount of attention is more than balanced by having a resistance that will not burn out however heavily it is overloaded. The objections that are urged against it are: *First*, bad insulation caused by the liquid creeping and spraying on to the porcelain insulators. This need not happen if the box is covered and the insulators are placed where they can be easily got at for cleaning. *Secondly*, too heavy a current at the moment of starting. This refers to motors working on some of the town lighting mains, or to small high-voltage motors for which the liquid resistance is certainly not suited. For powers of five horse and over at 230 volts, or for ten horse-power at 500 volts, the resistance can very easily be regulated to give no more than full-load current for the start, and this, if it does not satisfy the station engineer, is quite good enough for any properly constructed motor. *Thirdly*, the generation of explosive gases has alarmed some of our fire insurance experts; but when one remembers the very small volume of gas that is generated at each operation, it is difficult to believe that an explosion has ever been caused by this means, unless the resistance was not provided with a short-circuiting switch contact for the full-on position.

In order to give satisfaction to the general user, the liquid starter must be provided with an overload and a "no-volt" automatic release, just as has been done with the wire-wound switches. If a "no-volt" release cannot be used conveniently, the main double-pole switch must be interlocked with the resistance, so that the current cannot be switched on while the resistance is cut out.

The Sandycroft Foundry Company, Limited, have introduced a liquid resistance starter that has some novel features, and is undoubtedly a great advance on the old-fashioned makeshifts that we have been used to see. The liquid, which consists of common soda and water, is contained in a tightly closed cast-iron case, and instead of moving the plates in the usual way, the whole cylindrical case is rotated on an insulating bearing. A no-volt and also an overload automatic release is provided, and as the overload release acts not only in the full-on position, but also during the operation of starting, the

current cannot be turned on too suddenly. The makers state that at the moment when the plates enter the liquid the current is only from five to ten amperes in the case of a 10 H.P. starter, and that sufficient plate area is provided to pass the full-load current before the liquid is short-circuited. By completely enclosing the liquid, the evaporation is so much reduced that it need only be renewed at very long intervals.

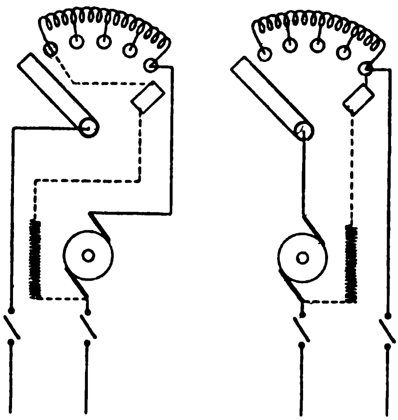


Fig. 1.

Connections.

There seems to be a difference of opinion as to the best way of connecting the resistances and the motor. The majority of makers arrange their switches for the armature to be connected to the last contact of the resistance. The main is then joined to the starting lever, and the shunt magnet is connected through the "no-volt" coil to the first contact of the resistance. The current is applied simultaneously to the magnets and armature, so that as the field builds the torque is applied gradually. Moving the switch lever over cuts the resistance out of the armature circuit and puts it into the field circuit. The shunt windings are permanently connected through the no-volt coil and resistances across the brushes, so that the self-induction kick spends itself gradually as the motor slows down. An alternative method is to connect the armature to the starting lever and to join both the main and the shunt magnet wires to the last or "full-on" contact of the resistance. The field is then excited when the main switch is closed, and the motor is started and stopped without demagnetising the magnets. When the lever touches the first contact the full torque is applied instantly to the armature, and this causes undue strains on the moving parts. A more serious weakness of this method of connection is that when the motor is at rest with the starting switch in the "off" position, the magnet windings are not connected across the brushes, and if the main switch is opened the kick of the magnets will be very likely to rupture the insulation of the field spools.

Switch Work.

In discussing the type of resistance that is best suited for a particular purpose, we found it convenient to distinguish between frequent and occasional use, and a moment's consideration will show that the same classification can be applied with advantage to the switch work. Where the switch is used often, as, for instance, with a printing press or with a machine tool, too much stress cannot be laid on the importance of strong construction with the contacts and all wearing parts renewable from the front; but for what we have called occasional use —the driving of a line of shafting, for instance, or a butcher's sausage machine—the use of a heavy switch construction is not necessary. The business of the engineer is to provide the best all-round economy, and it is possible to waste money by using plant that is more substantial than is necessary, just as certainly as it is a temptation to use stuff that is too light. The danger is that, if we admit a light switch construction in certain cases, some matters of vital importance may be neglected in a struggle for cheapness. For instance, there are switches on the market which no one would consider too substantial in their construction, whatever else might be said of them, in which the main current passes through the iron arm of the switch lever. There would be no objection to this if the contacts to iron were short-circuited in the "full-on" position instead of being, as they are, left always in circuit. Large numbers of these switches have found their way into this country, where they may be seen installed with a double-pole switch having drawn copper parts which are probably not allowed to carry more than eight hundred amperes per square inch, according to specification.

Switches that are to be exposed to the weather must have a watertight case not only for the resistances, but also for the switch work. The ordinary patterns of ironclad starters are admirably fitted to keep the damp away from the resistance wires, but they are seldom designed so as to admit of the addition of a cast-iron cover over the switch front, although this could easily be arranged for as an addition to standard patterns and at a very small extra cost.

Where covers are used the switch lever is sometimes brought out through a slot in the top of the case. It may cost a few shillings more to provide a separate handle bushed through the cover and engaging by a pin with the switch lever inside, but it is the only way to make a watertight job.

Examples of Starters.

Messrs. Cowans, Limited, of Manchester, are making a watertight switch on very novel and interesting lines. The resistances are made of strip coiled in a cast-iron box, each box containing one unit of resistance. These boxes are built in two tiers, and a screw with a quick pitch moves a connecting piece over the contact blocks that are attached to the resistance boxes. If a resistance burns out, a new one can be inserted with a minimum of trouble. The screw gives a slow motion to the starter, and this, combined with the waterproof and

generally substantial construction, makes it particularly fitted for places where it is exposed to careless handling.

Another example of a switch in which the resistance is divided into easily renewable units is the crane controller made by the Electric Controller Supply Company, of Cleveland, U.S.A. Each resistance is complete in itself, and is attached to the slate base by a hexagon copper nut which serves as a contact stud. The resistance wires are wound on asbestos tubes, and the apparatus is therefore only suited for dry positions, since asbestos absorbs water readily from the atmosphere, and loses its insulating properties if used in exposed places. The current passes through an iron rod that supports the asbestos tube, and the makers claim that iron is better than brass for this purpose, because it is magnetised by the current through the resistance spiral, and so provides a magnetic blow-out for the arc.

A departure is made from the usual electro-magnet for retaining the switch-arm in the full-on position in a starter supplied by the International Electrical Engineering Company. Instead of placing it at the free end of the switch lever, the "no-volt" coil is wound on an iron bobbin that forms the bearing of the switch spindle. When the starting resistances are also used to control the speed, this arrangement provides a no-volt release action that will hold the lever against the pull of the spring, not only on the last contact, but also on any intermediate position. Messrs. Ellison, of Paris, also make a combined starting and speed-regulating switch, in which the ordinary pattern of no-volt magnet is used in conjunction with two levers, one of which controls the current, and the other is held by the no-volt magnet against the action of the spring. When the current is switched off, this lever flies back and carries the other lever with it.

Messrs. Veritys, Limited, have made two standard lines of starters, one with the resistance spirals embedded in sand for starting on light load, or for what we have called occasional use on full load; and another construction for frequent use and for exceptionally severe conditions, in which the radiation type of resistance is used, the wire spirals being coiled round porcelain insulators and exposed to the air.

When an overload release magnet is not provided, the switch is made on the usual lines, but the shunt field connection is joined, not only to the first contact of the resistance switch, but also to the frame of the no-volt magnet coil, so that when the switch is in full-on position the starting resistances are not left in the field circuit, but are short-circuited. In the larger sizes, when the shunt current is too great to be safely passed through the iron magnet frame, a separate contact stud is provided for this purpose. The starters that are provided with an overload action have a single-pole switch in the armature circuit that is closed by moving the starting lever to the position in which the resistance is all in circuit, and is then held closed against the action of a spring by the no-volt magnet. The overload magnet acts in the well-known way by short-circuiting the windings of the no-volt magnet. If the starting lever is moved over too rapidly, the overload operates and releases the main switch, which then breaks the circuit, the arc being taken by carbon blocks. A unique feature of this starter is that the

spring pulls the switch lever to the "full-on" position, instead of to the off position as usual. In the larger sizes the contact plates are renewable from the front of the slate, and a carbon brush is used on the contact lever to protect the laminated copper brush and the part of the contact plates on which it moves from being roughened by the sparks.

Automatic Starters.

Motors driving pumps for charging hydraulic accumulators or for filling tanks require a special form of switch that will start and stop the motor automatically as the level varies. A common arrangement is to make the motion of the float throw over a switch in circuit with a solenoid. The starting lever is then moved over the contacts by the motion of the core as it is sucked into the solenoid. In order to give the necessary slow motion to the switch lever, dash pots have to be resorted to, and every one knows the troubles they introduce, either by wearing loose and working too fast, or sticking with a little bit of grit. The weakness of the solenoid and dash-pot arrangement is that if the dash pot does stick, or if the contacts of the switch become roughened with the arc, there is no reserve power in the solenoid to overcome the extra friction. Messrs. George Ellison have introduced a starting switch for this class of work in which the motive power for moving the switch is provided by a small cylinder and piston connected to the water mains. When the motor is required to start, the movement of the float turns on a small two-way cock which admits water into the cylinder. As the piston slowly rises it first closes a double-pole main switch, and then proceeds to cut out the resistance step by step. When the tank is full the float again throws over the two-way cock—connecting the cylinder to the drain pipe. The piston then falls rapidly under the action of a weight, first inserting the resistance and then opening the double-pole main switch. To prevent the contacts from being roughened by the arc, a magnetic blow-out is provided.

In conclusion, let me say that in these brief notes no attempt has been made to treat the subject systematically or as a whole, but rather to mention a few of the points of interest that have cropped up from time to time in selecting starters for different purposes; leaving a more adequate treatment to those who are directly concerned in the manufacture of this class of switch—to whom by right it belongs.

Mr. J. C. Vaudrey said that a very great deal of ingenuity had been displayed in the manufacture of starting-switches. Speaking as with a central-station engineer's experience, he might say that in Birmingham they had 400 or more motors on the town circuits, and the bulk of them were controlled by starting-switches. Many of these had been in existence three or four years and, in his experience, had given comparatively little trouble. The object of the starting-switch was to protect the consumer from spoiling his motor, but it was also absolutely essential to prevent undue draughts of currents for the moment on the supply system. The minimum and maximum was purely a question Mr. Vaudrey.

Mr. Vaudrey. for the consumer. The maximum cut-out protected the consumer from an accident to his motor through overwork, the minimum cut-out protected the consumer should the supply system for any short period cease.

He thought that with very large and heavy machinery, which sooner or later would be put upon the supply system, the starting-switches such as shown by Mr. Bate would not be sufficient. In Birmingham they were now dealing with two or three large printing presses, and in addition to the starting-switch a system was applied which gradually increased the current, so that there was not a sudden draught on the supply system. This was not only a supplement to the starting-switch, but in reality became an essential part of such machinery, and probably for motors of 40 H.P. or 50 H.P., where any sort of regulation was required, it would be used. With the cheapening of the supply and the advent of large motors of 40 H.P. or 50 H.P., it was quite clear that something beyond a mere starting resistance became necessary, and there were two methods in vogue. One was to start through a motor-transformer termed a "teaser," which reduced the current to a low voltage with a corresponding increase of amperes; the current was switched on, in the first instance, to this "teaser," which was afterwards cut out when the necessary start had been made. The second method of driving was, he thought, one more likely to come into use. This was a parallel-series system, the motor being fitted with two armatures on one spindle for working in series or parallel; these were joined in series for making the start, and afterwards changed over in parallel when a higher speed was desired, or when the machine became fully loaded. By those means 50-H.P. or 60-H.P. motors were readily put on the mains without trouble. After emphasizing the importance of the exposed parts of starting-switches being covered up, and predicting that for large powers nothing else than the covering to be seen on a tramway controller would sooner or later be allowed in factories, Mr. Vaudrey said that such apparatus could not be too well protected, because in town systems all motors of 5 H.P. and above would have to be supplied at 440 volts or higher pressure. The tramway starting-switch was a type which might very readily be copied. They were handy and of a form that workmen could understand, and they were very substantial. He had frequently noticed that the gear and the handles of ordinary starting-switches were anything but strong, and not what the ordinary mechanic was accustomed to deal with. He did not know what the condition of the Woolliscroft water starter shown would be if the water boiled up unless there was a safety-valve.

Mr. Cowan. Mr. E. W. Cowan said that he quite agreed with Mr. Bates in his commendation of the absorption type of resistance as being the best. Properly made, it was by far the most mechanical form of resistance. The open spirals were necessarily weak, and the methods of supporting them difficult, and the economy in first cost was very considerable.

In connection with the starters made by his own firm, a test was recently made of the relative capacity of an open spiral resistance and a resistance of exactly the same length and size in every respect made in the form of their thermal capacity resistance. The result was that

while the spiral with 1 H.P. on it became red-hot in a quarter of a minute, the thermal capacity unit in two minutes showed no sign of any high temperature sufficient to cause it to radiate any light. That the absorption type of resistance had a very bad name with some of the consulting engineers in this country was due to the fact that a breakdown was such a serious thing, involving great loss when a motor was driving a large number of machines. The starting-switch made by his firm, which was shown by Mr. Bate, was one of nearly a hundred made for the railway shops at Pretoria. He was very much interested in the liquid resistance, and hoped to know more about it before he left the meeting. He should be surprised if the manufacturer had succeeded in getting no jump between the equivalent of the last stop of the resistance and all resistance out. It was very difficult to get it in liquid starters, and also, at the same time, to get sufficiently small current to start with. He thought liquid starters were better suited than any other form for hoist and crane work. There was of course the difficulty of corrosion, but in cases where the starters were in the hands of people who knew nothing at all about electricity, they should be as durable as they could possibly be made. Mr. Cowan pointed out that in his firm's starter the full field was on at the commencement. He thought the full field should come on at first so that the starting current was as small as possible. He would conclude with a list of points that he thought every motor starter of any size should conform with. He agreed that excessive finish was out of place; what was wanted was substantial construction. He thought the starter should be made on the same lines as the motor, with the same regard to durability, and that that would be cheapest in the long run. All the working parts should be enclosed, not only in the interests of safety, but because in workshops switches with parts exposed got broken. The other points were as follows:— Mr. Cowan.

(1) Designed as a machine, and not as an instrument, and equally capable of standing the same treatment as the motor it is to control. (2) Resistance units of uniform shape and dimensions, and interchangeable, connected directly to the contact studs by lugs on the units. (3) Resistance units either of the ventilated type for controlling purposes, or of the capacity type for starting only, as required. No structural alteration necessary in the starter for either type. (4) Large number of contact studs, making any arc-quenching device unnecessary. (5) Slow-moving contact brush operated by deep-cut screw shaft of large diameter. (6) Spring return of contact brush to "off" position by means of large spiral spring on main screw shaft. (7) Speed of screw shaft when released controlled by simple centrifugal governor which absorbs the energy of the revolving parts gradually without introducing static friction; and, therefore, no violent shock when the brush is brought to rest. (8) No sliding contact-bars or flexible connections, as by a special method of arranging the resistance units no connection to the main brush was required. (9) Resistance scientifically graduated for best conditions of starting. (10) No solder used on resistance units, joints made by electric welding.

The diagram (Fig. A) shows the arrangement of the resistance and

Mr. Cowan. connections of the starter. The resistance units are arranged in two batches, each directly connected to a row of steps, the cursor-brush simply bridging over the two rows of stops, thus avoiding all flexible or sliding connections to it. The lamp shown in the diagram serves the double purpose of a cushioning resistance for the field, and also to indicate when the motor has started, and the speed at which it is running, the candle-power being gradually reduced as the back E.M.F. of the armature balances the E.M.F. of supply. Thus a motor can be started

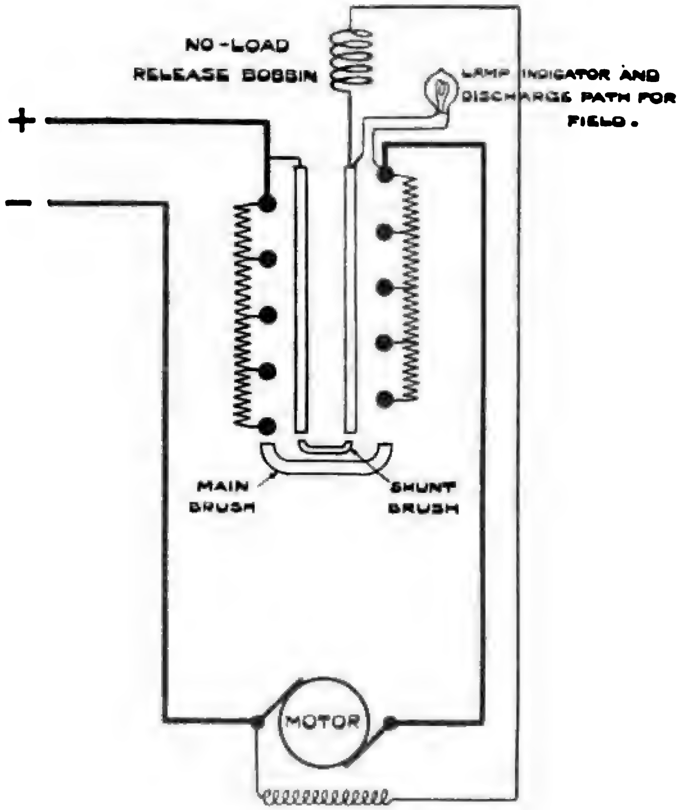


FIG. A.—Diagram of Connections, Cowan's Patent Motor Starter.

at a distance, and its behaviour observed by the brightness of the lamp. The lamp also indicates that all connections are in order, and current on the starter. This lamp is cut out when the motor is running at full speed.

Mr. Woolliscroft. Mr. J. H. WOOLLISCROFT said that he should like to question and clear up the points and objections raised in the discussion in regard to liquid switches in general, and to the one of his own patented design exhibited at the meeting.

Mr. Vaudrey had remarked that he would not care to start up a motor with the enclosed 5-B.H.P. type of liquid switch shown, as it might boil over. In the first place this switch was only for the purpose of starting up, say at the most 10 times per hour or every six minutes, when at the end of that time it would hardly be warm, but if a controller, or rather a regulator, were required, the size used would be much increased. If a starter were used as a regulator it would get so hot as to boil, and eventually evaporate to dryness, but that would be all, and it would not be burnt out as an ordinary wire starter, used for continuous regulation. There was a relief valve fitted on the case which allowed the small amount of gas made in starting up to escape at once; the hydrogen, being so much lighter than air, escaped during the process of starting up. Although these switches were of an entirely new type, they had been tested under working conditions for some months, and had given the greatest satisfaction. Repeat orders constantly received spoke for themselves, and proved that in practice it had been found a cheap, reliable starter, regulator, or reverser, as the case may be. Mr. Woolliscroft.

In reply to Mr. Cowan, as to the trouble of kick to the motor in short-circuiting when the blade was entirely cut out and the switch short-circuited, the blade area was very liberal, and there was an additional augmenting blade close to the side of the case, and, therefore, when the blades were fully in, that is, as in a wire resistance on the last resistance stop, the resistance between this point and the short-circuiting position was so small that the kick or jump produced by the final short-circuiting of the starter was negligible. Replying to a query put by one of the speakers, he said that for different voltages up to 700 volts the same switch is used, only the density of liquid must be altered to correspond—for the lower pressure, a larger percentage of caustic soda; and for a higher pressure or voltage, a weaker solution. These switches had been supplied up to 60 B.H.P. equipped with overload and minimum releases, and they had not had the slightest complaint in regard to them. An outside current-breaker was not required; they were also non-inductive. Another feature was that, as the blade rotates with a circular movement in switching off, there was, for a second or so, a rapidly diminishing film of liquid leaving the blade tip, and thereby throwing in a very high resistance before opening the circuit. He believed that in this liquid switch the usual troubles of liquid switches had been entirely eliminated.

Mr. LIONEL E. BUCKELL said he thought the importance of starting-switches had, if anything, been underrated by Mr. Bate. Most of those who had had much to do with continuous-current motors would probably consider the starting-switch more likely to give trouble than the commutator. Station engineers in making regulations governing the use of motors did not seem to realise that they were putting obstacles in the way of developing their motor-load with very little advantage to their lighting supply. The suggestion as to rating appeared very valuable, and it was to be hoped that manufacturers would adopt this or some other standard system by which all starting-switches could be compared. There might be a difficulty in the small Mr. Buckell.

Mr. Buckell. wire at the "all-out" end in carrying the full current for half a minute. The absorption type of resistance was an exceedingly troublesome piece of apparatus to repair, and with a starting-switch ease of repair would seem to be more important than the little extra protection afforded. Mr. Bate did not refer to the importance of the material of which the resistance was made, and to the importance of providing sufficient radiating surface. Many of the iron-wired resistances wound on asbestos tubes, in the speaker's experience, gave great trouble due to rusting, and had to be replaced by platinoid wound on slate, which gave no trouble. Mr. Bate's second method of connecting up the switch appeared in practice to give most satisfactory results. Commercial motors seemed to have sufficiently strong insulation on the fields to stand the kick. The strain on the armature due to the torque being applied suddenly was not so serious as the trouble caused by blowing fuses when starting up on a load having heavy inertia in the first method. The overload attachment seemed to be a very doubtful advantage for sizes above 7 or 8 H.P., and a separate magnetic circuit breaker instead of one of the main switches gave much more satisfactory operation, the expense not being very great.

Mr. Brown. Mr. F. BROWN said he did not agree with what Mr. Vaudrey had said as to small motors not requiring starting switches. For he found that the small motors got worse usage than the larger ones, because they were put in less skilled hands, and if they had not a protecting arrangement as to over-load there would be a great deal more trouble than there was.

Mr. Vaudrey. Mr. VAUDREY said that he was referring to the starting of motors of not more than a quarter or half horse-power.

Mr. Brown. Mr. BROWN, proceeding, said he had found liquid resistance-switches very useful for intermittent work, particularly on organ blowing and work of that nature.

Mr. Hunt. Mr. F. O. HUNT said that he could not agree with some of the speakers that the central station engineer was wrong in requiring some sort of limitation on the sudden demand that was to be made on his mains. It would, however, be much better for the manufacturers if the station engineers would arrive at some notion of uniformity as to the extent of this limitation. He also blamed the consulting engineers, who were generally too vague in their statement of the condition to be met. He was in favour of standard rating, but suggested a subdivision of Class I. into full and half-load starters. It was possible to economise if it were specified that the motor would not be required to start up against full load. He advocated a single time test which should give temperature conditions equivalent to the intermittent test proposed in the paper. He thought the character of the test should be based upon the idea of a factor of safety with regard to the time of carrying current, and the factor should be greater in the case of small motors than with large ones, owing to the less skilled handling to which the former are usually subjected.

Mr. Bornand. Mr. VICTOR BORNAND said that the greatest evil was that contractors contented themselves too often with buying light work instead of a sound and reliable apparatus which would always give them satisfac-

tion if they would increase a little more the initial outlay. Armatures were often damaged and burnt out by a badly built motor-starter. Mr. Bornand.

Rating of resistances would avoid many troubles if the specification suggested was followed by every one, and if specially more attention was given to the specification of motor-starters.

The liquid-resistance type of starter was very old indeed, but it could not possibly be compared with metallic starters, which, if they were properly built, did not require any maintenance whatever. To this type of starting gear mentioned, he might perhaps add a similar type of starter, but in which the water was replaced by graphite powder, and it seemed to give very good results.

Of the two different ways of making connections of motor-starters the first, viz., to connect by the shunt magnet through the coil and first contact of the resistance, was that usually adopted. If the second ring contact on the starter was omitted, this mode of connection had the serious drawback that the shunt coil was connected through the starting resistances. This had, first, the effect of raising the speed of the motor about 5 per cent., and, secondly, a dangerous drawback of having the shunt field permanently connected through the starting resistance when the motor is running. Should overheating happen in this resistance (which was composed of wires of different sizes with many junction points and delicate parts) it might get out of order very quickly; and if bad contact through the resistance happens, the armature would simply be a direct short-circuit on the mains.

Referring to the second mode of connection, viz., by connecting the shunt coil to the last contact of the resistance, it presented certain practical advantages, chiefly in not having the field connected through the starting resistance, and that in closing the double pole switch the field of the motor was ready; then by the starting resistance current is gradually supplied to the armature. In stopping the motor no danger was to be expected from the inductive kick of the magnet, as if the double pole switch were opened the remanent magnetism of the no-volt coil would still hold the motor-starter lever in position and the inductive current would discharge through the armature, which would still be running for a few seconds. The kick of the magnet was about four times higher than the voltage of the main, and too much importance might be given to it as it would be a very poor motor if it had a field of so poor insulation that it would not stand the kick of the magnet.

Mr. S. E. Glendenning said that there were now many devices for preventing any mistake being made except by the switch itself. But when full-load current was allowed on the first step, the switch had, in many cases, to be moved very slowly to prevent a much larger rush of current—reminding one of an alternating-current motor. Mr. Glendenning.

Mr. H. F. Hunt said that one or two of the speakers had referred to the drawback of having the shunt connected to the first contact of the resistance on the ground that the field builds up slowly and that therefore the motor cannot start until current has been passing for some time. With large machines it might be so, but in smaller ones the field grew so rapidly that the effect was inappreciable. He recently took some measurements from a 10-H.P. 440-volt ironclad motor having Mr. Hunt.

Mr. Hunt. a normal field current of 1·1 ampere. One second after switching on the shunt, the current was approximately 0·70, in two seconds 0·95, in three 1·08, in four 1·095, and after five seconds 1·1. The field rose to within 5 per cent. of its full value in about two and a half seconds. There was an advantage in connecting both shunt and armature together on the starter.

A good method of testing the starting switch, and one which his firm had adopted, was to connect the starter in series with a special liquid resistance across the full line voltage, and then while one man moved the starting lever over at any required rate, another man kept the current at full-load value—or some fixed amount—by adjusting the liquid resistance. This gave a fair test to the coils at both ends of the starter. Mr. Vaudrey mentioned that for ¼- or ½-H.P. motors no starters were necessary. In such cases an ordinary ½-H.P. shunt-motor would take about ten times its full current at the instant of being switched on to the supply.

A point which some engineers failed to realise was that a motor can always be started from rest sparklessly with a current far in excess of the current which would produce sparking at full speed. This, of course, was due to the reduction of cycles per second in the coils undergoing commutation at the brushes.

In regard to the difficulty of repairing the absorption type of starter, a properly constructed resistance box filled with sand was almost, if not quite, as easy to get at and put right as a set of spirals boxed in with a ventilated cover. Enamel or china rheostats, on the other hand, were almost incapable of repair. Unless a starter were intended for fairly frequent use, the temperature rise would not be very materially different whether it was ventilated or not, since the heat was all generated before any appreciable quantity had time to be radiated.

Mr. Bate. Mr. BATE, replying to the discussion, said most of the speakers seemed to be at variance with him with regard to the connections, but they had not succeeded in convincing him. If for motors smaller even than Mr. Hunt had mentioned, the shunt field rose in half a second, it was not at all in the nature of a blow and did not strain the parts to anything like the same extent as the force applied suddenly with only the self-induction of the armature to retard the current. He quite agreed with Mr. Bornand when he said that if the resistance was left in circuit with the shunt field with so many contacts which were or might be loose, and also in view of the fact that the speed was increased by nearly 5 per cent., it would be very objectionable. But it was a very common thing to short-circuit that resistance through the iron frame of the no-volt magnet coil. For larger motors where the iron did not provide sufficiently good contact an auxiliary contact stud served the purpose. With regard to the full-load current being passed on the first contact, unless the switch was used on central stations mains where there were special rules in force, he thought that for motors of moderate power up to, say, 10 H.P. full-load or even one and a half times full current was allowable, if the motor was properly constructed and had proper sparking limits. In testing motors properly designed from the commutation point of view he had not found any difficulty in

starting up with full-load current. Mr. F. O. Hunt thought the three classes he proposed were not enough. That might be so, but he (Mr. Bate) certainly thought that three classes were better than none. Of course he did not propose that that test should be applied to every motor starter that was made, but that the makers should state that the particular size of starter having already stood such a test would stand it again. Mr. Bate.

Mr. Buckell had pointed out that resistances were generally graded. That was so, but if full-load current were passed through the first contact, and it then had to pass through all the wires, the finest and the coarsest, when the motor speeded up the resistance was cut out, and he took it that no more than full-load current should in the ordinary course of events be put on to any contact or passed through any of the wires. If the starter were tested with the lever on the first contact and full-load current passed through it, with the precaution of the over-load for one test, he thought that would be quite sufficient. Mr. Vaudrey mentioned the American teaser system and the series-parallel motors as being likely to be the future methods of starting large motors. Those methods were very useful indeed where speed-control was necessary; that was a problem quite distinct from starting, and he must say he thought such methods would be too expensive for use in starting only. It certainly would be a great nuisance if they had to make all large motors with two commutators, or provide an auxiliary motor, in order to get another motor running—an auxiliary that only had to be used a few times a day. With regard to the drum-type of starter, of which Mr. Vaudrey spoke rather favourably, he (Mr. Bate) did not think they were suitable for use in ordinary cases as starters, because it was necessary to have the resistance separate from the switch, and that involved the use of many loose connecting wires which were objectionable. You wanted your starter to be self-contained. He was interested in Messrs. Cowan's radiation type of resistance. The sample on the table was in the ordinary way a 30-H.P. motor-starter which was now reduced to a 5-H.P. starter to meet a special specification. That illustrated how money might be squandered if they did not take proper care in getting the specification of the starter properly drawn out for the particular conditions that it had to fulfil.

ORIGINAL COMMUNICATION.

SOME NOTES ON HEAT-RUNS.

By F. W. CARTER, M.A., Associate.

Probably the most important test of a piece of electrical apparatus, whether from the point of view of engineer or purchaser, is the service test, or "Heat-run." In this the apparatus is loaded, as nearly as is practicable, to the same extent as it is likely to be when in operation, and is kept so loaded until the final steady condition corresponding to continuous service is attained. If this test develops no indications of a fault, we may conclude that the apparatus will at least stand the service for which it is intended. The usual sign of probable future trouble is high local temperature, and thus the most important part of a heat-run is the determination of temperatures of various parts of the apparatus.

Although such a test requires no high powers of observation, there is, nevertheless, great difficulty in obtaining consistent results on account of the number of conditions—some of them quite indeterminate—affecting the results. Where it is merely a question of discovering whether a machine of known type, and so of approximately known service rating, has any abnormal features, great accuracy is not necessary, for outside conditions will not usually be sufficiently active to affect general conclusions. But where service tests on a perfectly normal machine are to be made the basis of future developments, or to be employed in predicting the performance of the machine in any class of service that may arise, it is of the utmost importance to determine to what extent the several tests are affected by particular circumstances, and, where possible, to allow for these circumstances.

The author, having had occasion to work on a class of service test which requires all the accuracy that can be attained, whilst being subject to many disturbing influences, has developed certain methods of treatment which it will probably be well to place on record for the benefit of those engaged on similar work, since the same methods apply, to a greater or less degree, to heat-runs generally. The tests referred to are service tests of railway motors—a class of work which has been highly developed by the General Electric Co., being carried out on their experimental railroad at Schenectady.

These tests, being made out of doors, are particularly liable to be affected by atmospheric influences, some of which—such as wind and damp—produce effects that can only be estimated, and are best avoided when possible by a proper choice of the day of test. Again, the source of power is likely to vary, especially if it carries other load besides the running of the test. Then, unless some form of automatically accelerating controller is used, a change of motorman will probably alter the accelerating current. These and other things can be varied much faster than the temperature

which depends on them can follow. The ideal test would determine the temperatures corresponding to a steady and constant set of conditions; the actual test determines the temperatures corresponding to a set of variable conditions, and our present business is to show how to find the set of constant conditions which would be competent to produce the same heating as the actual variable conditions do produce.

In order to fully appreciate the importance of the following calculations, it is necessary to understand the object and use of the tests. The method used in working them up is indicated in a recent paper by A. H. Armstrong,* and need not be given at length here. Briefly, we determine the final temperature rise of both armature and field magnet coils, corresponding to continuous operation on a definite schedule with a definite weight of car or train, maintaining, as nearly as practicable, uniform voltage and accelerating current. Resistances of armature and field magnet coils, and all the temperatures that can conveniently be obtained are taken hourly, until practical constancy is reached. A number of records of current and voltage are made during the run by means of railway recording instruments, especially designed for such work, and from these we deduce the mean losses in iron and copper of both armature and field magnet. From a series of such runs the thermal characteristic curves of the motor are drawn. These are plotted between ratio of armature loss to field magnet loss as abscissa, and temperature rise per mean watt loss as ordinate—there being one curve for the armature and another for the field. If now it is proposed to use the type of motor for a certain service the losses in armature and field magnet incident to the service are computed. Then, from the ratio of distribution of the losses, the temperature rise per watt loss is found from the thermal characteristic curves, whence the actual temperature rise in armature and field—assumed proportional to the loss. Thus is predetermined whether the motor is competent to undertake the service in question. It is obvious that these thermal characteristic curves are of the utmost importance to the engineer. The tests required to obtain them are expensive, and warrant considerable pains being taken to render the results as reliable as possible.

Of disturbing influences, indeterminate ones, such as wind and rain, are avoided as far as possible by always electing to run on a still and dry day. The air temperature, however, will usually vary during the run, often dropping 5 to 10° C. as evening approaches. The motor only follows this variation very slowly, and it becomes necessary to determine an equivalent air temperature, such that the excess of the motor temperature above it is the true rise corresponding to the losses.

The voltage again may vary considerably during the day—though it is naturally more satisfactory if it can be kept constant—and if it does vary, we have to find the equivalent voltage that would lead to the observed final temperatures. Then, too, the time occupied in taking resistances and temperatures is likely to vary from hour to hour, or an accident may stop regular running for a period, and so we have to determine the equivalent value for the time so lost per hour

* "A Study of the Heating of Railway Motors," by A. H. Armstrong, *Trans. Amer. Inst. Elec. Engs.*, vol. xix.

that would lead to the temperatures actually observed. These are the chief of the variable factors affecting runs of this kind, but the methods employed in dealing with them will be found generally applicable to any such variable factors. We may note that the equivalents so found differ from the simple mean of the readings, and may differ considerably from it. If, for instance, the voltage is low for an hour near the end of the run, the effect on the final temperature will be considerably greater than if it were equally low for an hour some time before the end. In finding the equivalent, therefore, we have to give the greater weight to a reading the nearer it is to the end of the run, and we may describe our present problem as that of determining the weight to be given to a reading according to its position in the run.

The nature of the test, however, does not permit of greater accuracy than is obtained by taking the mean of the readings during an hour as the true value for that hour; that is, we divide the time of running into hours, and give equal weight to all readings in any particular hour.

If θ is the average temperature of the machine at time t, and T the air temperature, w the watts lost, or converted into heat in the machine, and R the watts radiated and convected from it, then $w - \mathrm{R}$ is the rate at which the amount of heat in the machine is accumulating, varying as the rate of rise of temperature, say, $= \mathrm{K}\,\frac{d\theta}{dt}$.

Now, R varies as the excess of the machine temperature over that of the air outside, say, $\mathrm{R} = k\,(\theta - \mathrm{T})$. Hence

$$\mathrm{K}\,\frac{d\theta}{dt} = w - k\,(\theta - \mathrm{T}),$$

$$\text{or} \quad \frac{d\theta}{dt} + p\,\theta = p\,\mathrm{T} + p\,\frac{w}{k}, \qquad \ldots\ldots \qquad (1)$$

$$\text{writing } \frac{k}{\mathrm{K}} = p.$$

Now, if T and w were constant ($= \mathrm{T}'$ and w' say), this would integrate to—

$$\left.\begin{aligned} \theta &= \mathrm{T}' + \frac{w'}{k} - \left(\mathrm{T}' + \frac{w'}{k} - \theta'\right) \epsilon^{-pt} \\ \text{or} \quad \theta &= \theta'\,\epsilon^{-pt} + \left(\mathrm{T}' + \frac{w'}{k}\right)\left(1 - \epsilon^{-pt}\right) \end{aligned}\right\} \qquad \ldots\ldots \qquad (2)$$

where θ' is the temperature of the machine when the regular load is put on (*i.e.*, when $t = o$). The term involving ϵ^{-pt} becomes smaller as t becomes larger, and its becoming practically negligible is the condition that a constant temperature is attained, and the heat-run may be brought to a close. We can shorten the run accordingly by making the coefficient of ϵ^{-pt} small, that is, by heating the machine (by means of an overload, say) until its temperature nearly reaches the final steady value corresponding to the regular load. [Note that with different

machines the minimum length of the heat-run varies as $\frac{1}{p}$.] Thus, the final temperature when the term in ϵ^{-pt} has become negligible is

$$\theta = \mathrm{T}' + \frac{w'}{k} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

When, however, T and w are functions of t, the integral of 1 becomes

$$\theta = \theta' \epsilon^{-pt} + p\,\epsilon^{-pt}\int_0^t \mathrm{T}\,\epsilon^{pt}\,dt + p\,\epsilon^{-pt}\int_0^t \frac{w}{k}\,\epsilon^{pt}\,dt \quad . \quad . \quad . \quad (4)$$

Thus, if we take T′ and w' as equivalent values, competent to produce the same final temperatures as are actually reached, we get by equating the values of θ from equations (2) and (4)—

$$\left(\mathrm{T}' + \frac{w'}{k}\right)\left(1 - \epsilon^{-pt}\right) = p\,\epsilon^{-pt}\int_0^t \mathrm{T}\,\epsilon^{pt}\,dt$$

$$+ p\,\epsilon^{-pt}\int_0^t \frac{w}{k}\,\epsilon^{pt}\,dt,$$

whence—

$$\mathrm{T}'\left(1 - \epsilon^{-pt}\right) = p\,\epsilon^{-pt}\int_0^t \mathrm{T}\,\epsilon^{pt}\,dt \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$w'\left(1 - \epsilon^{-pt}\right) = p\,\epsilon^{-pt}\int_0^t w\,\epsilon^{pt}\,dt \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

In these equations time is measured from the beginning of the regular run onwards towards the end. We shall find it more convenient for our purpose, however, if we measure time from the end of the run towards the beginning. Equations (5) and (6) then become—

$$\mathrm{T}'\left(1 - \epsilon^{-pt}\right) = p\int_0^t \mathrm{T}\,\epsilon^{-pt}\,dt \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

$$w'\left(1 - \epsilon^{-pt}\right) = p\int_0^t w\,\epsilon^{-pt}\,dt \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

The task before us is now that of evaluating these integrals. We note that equations (7) and (8) are of similar form, so that the same method can be used to determine either the equivalent air temperature or the equivalent motor loss. Conducting the argument in the language of losses, let w_1 be the mean loss during the last hour of the run; w_2 that during the hour preceding the last; w_3 that during the next preceding, and so on, and assume that during any particular hour, or other suitable unit of time, the loss remains uniform at its mean value. Then—

$$p\int_0^t w\epsilon^{-pt}\,dt = p\,w_1\int_0^1 \epsilon^{-pt}\,dt + p\,w_2\int_1^2 \epsilon^{-pt}\,dt + p\,w_3\int_2^3 \epsilon^{-pt}\,dt + \ldots$$
$$+ p\,w_n\int_{n-1}^{n} \epsilon^{-pt}\,dt$$
$$= w_1(1-\epsilon^{-p}) + w_2(\epsilon^{-p}-\epsilon^{-2p}) + w_3(\epsilon^{-2p}-\epsilon^{-3p}) + \ldots$$
$$+ w_n(\epsilon^{-\overline{n-1}p} - \epsilon^{-np})$$

Thus writing $q = \epsilon^{-p}$ we get—

$$w'(1-q^n) = w_1 + q(w_2 - w_1) + q^2(w_3 - w_2) + \ldots$$
$$+ q^{n-1}(w_n - w_{n-1}) - q^n w_n \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

This gives the equivalent loss in terms of the readings and the quantity q, which depends on the motor, and of which more will be said hereafter.

Suppose now the variation in loss is due to varying voltage. If this variation is not excessively large, we may, without great error, assume that the change in watts is proportional to the change in voltage. This is the same as supposing that the watt-volt curve practically coincides with its tangent in the neighbourhood of the point where we are working. Thus, writing $w = \alpha V + \beta$, we get from equation (9)—

$$(\alpha V' + \beta)(1-q^n) = \alpha V_1 + \beta + q\,\alpha(V_2 - V_1) + q^2\alpha(V_3 - V_2) + \ldots$$
$$q^{n-1}\alpha(V_n - V_{n-1}) - q^n(\alpha V_n + \beta)$$

or—

$$V'(1-q^n) = V_1 + q(V_2 - V_1) + q^2(V_3 - V_2) + \ldots$$
$$+ q^{n-1}(V_n - V_{n-1}) - q^n V_n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

the same form as equation (9).

Suppose again that the variation in loss is due to variation in time of stoppage, for taking temperature or other cause. The mean loss is proportional to the time the regular schedule is being made, or to $60 - t$, where the time lost is t minutes per hour. Hence from equation (9)—

$$(60 - t')(1-q^n) = 60 - t_1 + q(t_1 - t_2) + q^2(t_2 - t_3) + \ldots$$
$$+ q^{n-1}(t_{n-1} - t_n) - q^n(60 - t_n)$$

or—

$$t'(1-q^n) = t_1 + q(t_2 - t_1) + q^2(t_3 - t_2) + \ldots$$
$$+ q^{n-1}(t_n - t_{n-1}) - q^n t_n. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

again the same form as equation (9).

Having in this way obtained equivalent values of the several factors affecting the losses, we use these in computing the losses to which the observed temperatures correspond.

The air temperatures are read hourly, so that if the readings are $T_0, T_1, T_2, \ldots T_n$ (beginning from the end of the run), the mean temperatures for the several hours are $\frac{T_0 + T_1}{2}$, $\frac{T_1 + T_2}{2}$, etc. Thus the equivalent air temperature is given by—

$$T'(1 - q^n) = \frac{T_0 + T_1}{2} + q\left(\frac{T_1 + T_2}{2} - \frac{T_0 + T_1}{2}\right)$$
$$+ q^2\left(\frac{T_3 + T_2}{2} - \frac{T_2 + T_1}{2}\right) + \ldots q^n \frac{T_{n-1} + T_n}{2}$$

$$= \tfrac{1}{2}\{T_0 + T_1 + q(T_2 - T_0) + q^2(T_3 - T_1) + \ldots$$
$$+ q^{n-1}(T_n - T_{n-2}) - q^n(T_{n-1} + T_n)\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

This is the air temperature that should be used in calculating temperature rises.

Although I consider equation (12) sufficiently accurate to suit the requirements of heat-runs, I will give a more accurate solution of the same problem, partly because an exceptional case may call for greater accuracy, but principally because the question of equivalent air temperature is not connected exclusively with heat-runs, but may arise in laboratory tests, capable of high accuracy. While in the above we have assumed that the temperature in the interval of time between two readings remains constant at the mean of the readings, we will now suppose that the temperature-time curve is composed of straight lines joining the readings—which assumed curve is never likely to be far from the true temperature-time curve. We will suppose, as before, that the readings are taken at equal intervals of time, and will take the common interval as our unit. Thus, referring to equation (7), suppose that the air temperature between times o and 1 is given by

$$T = T_0 + (T_1 - T_0)\,t\,;$$

between times 1 and 2 by

$$T = T_1 + (T_2 - T_1)(t - 1),$$

and so on. Now

$$p\int_0^1 [T_0 + (T_1 - T_0)t]\,e^{-pt}\,dt = T_0(1 - e^{-p}) + (T_1 - T_0)\left(\frac{1 - e^{-p}}{p} - e^{-p}\right)$$
$$= T_0 + \frac{T_1 - T_0}{p} - \left(T_1 + \frac{T_1 - T_0}{p}\right)e^{-p}$$

$$p\int_1^2 [T_1 + (T_2 - T_1)(t - 1)]\,e^{-pt}\,dt = \left(T_1 + \frac{T_2 - T_1}{p}\right)e^{-p}$$
$$- \left(T_2 + \frac{T_2 - T_1}{p}\right)e^{-2p}$$

$$\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$

$$\therefore\ T'(1 - e^{-np}) = T_0 - T_n e^{-np} + \frac{1}{p}\Big\{(T_1 - T_0) + (T_2 + T_0 - 2T_1)e^{-p}$$
$$+ (T_3 + T_1 - 2T_2)e^{-2p} + \ldots + (T_n + T_{n-2} - 2T_{n-1})e^{-(n-1)p}$$
$$- (T_n - T_{n-1})e^{-np}\Big\}$$

or—

$$T'(1-q^n) = T_0 - T_n q^n + \frac{1}{p}\Big\{T_1 - T_0 + (T_2 + T_0 - 2T_1)q + (T_3 + T_1 - 2T_2)q^2 + \ldots + (T_n + T_{n-2} - 2T_{n-1})q^{n-1} - (T_n - T_{n-1})q^n\Big\} \quad \ldots \ldots \quad (13)$$

The calculation of T′ from this equation is not difficult if systematically performed. The arrangement on page 1111 enables the equivalent air temperature to be found for every hour during the run.

It will be found that a small error in the value of q will have very little effect on the results; nevertheless it is such a frequently recurring quantity that we naturally seek to determine it as accurately as possible. If a number of runs are made on a particular type of motor, we can usually find one in which—for part of the run at any rate—there has been a considerable rise or fall in temperature, while circumstances affecting the final temperature have remained approximately constant. To such a run we can apply equation 2 to determine q or ϵ^{-p}. Thus, let θ_1, θ_2, and θ_3 be consecutive readings of temperature, corresponding to times t, $t+1$, and $t+2$ (the unit of time being the common interval between readings), then—

$$\theta_1 = T' + \frac{w'}{k} - \left(T' + \frac{w'}{k} - \theta'\right)q^t$$

$$\theta_2 = T' + \frac{w'}{k} - \left(T' + \frac{w'}{k} - \theta'\right)q^{t+1}$$

$$\theta_3 = T' + \frac{w'}{k} - \left(T' + \frac{w'}{k} - \theta'\right)q^{t+2}$$

$$\therefore \quad \frac{\theta_3 - \theta_2}{\theta_2 - \theta_1} = \frac{\left(T' + \frac{w'}{k} - \theta'\right)q^{t+1}(1-q)}{\left(T' + \frac{w'}{k} - \theta'\right)q^t(1-q)} = q \quad . \quad (14)$$

If the conditions remain constant for four or six units of time, we shall obtain greater differences in temperature, and therefore greater accuracy, if we take the readings θ_1, θ_2, and θ_3, two or three units of time apart. If they are separated by two units, equation 14 gives q^2 instead of q, and if by three units q^3, and so on.

Again—

$$q = \epsilon^{-p}$$

$$\therefore p = \log_e \frac{1}{q} = 2{\cdot}3 \log_{10} \frac{1}{q}$$

Again, remembering that the final temperature (θ) is $\theta = T' + \frac{w'}{k}$, we get—

$$\frac{\theta - \theta_1}{\theta - \theta_2} = \frac{\theta - \theta_2}{\theta - \theta_3} = \frac{1}{q}$$

giving—

$$\theta = \theta_3 + \frac{(\theta_3 - \theta_2)^2}{2\,\theta_2 - \theta_1 - \theta_3}.$$

	T_0	T_1	T_2	...	...	T_{n-1}	T_n
 q q^2 q^3 q^{n-1} q^n	$T_1 - T_0 (= \tau_1)$ $q\ (\tau_2 - \tau_1)$ $q^2 (\tau_3 - \tau_2)$ $q^3 (\tau_4 - \tau_3)$ ... ... $q^{n-1} (\tau_n - \tau_{n-1})$ $- q^n \tau_n$	$T_2 - T_1 (= \tau_2)$ $q\ (\tau_3 - \tau_2)$ $q^2 (\tau_4 - \tau_3)$ $q^3 (\tau_5 - \tau_4)$ ... ... $- q^{n-1} \tau_n$	$T_3 - T_2 (= \tau_3)$ $q\ (\tau_4 - \tau_3)$ $q^2 (\tau_5 - \tau_4)$	... ...	... $q\ (\tau_n - \tau_{n-1})$ $- q^2 \tau_n$	$T_n - T_{n-1} (= \tau_n)$ $- q\ \tau_n$	T_n $q\ T_n$ $q^2 T_n$ $q^3 T_n$ $q^{n-1} T_n$ $q^n T_n$
	← The Algebraic sum of the several columns						
	← The same divided by p →						
	$T_0 - T_n q^n$	$T_1 - T_n q^{n-1}$	$T_2 - T_n q^{n-2}$	...	...	$T_{n-1} - T_n q$	T_n
	The sum of the last two lines =						
	$T'_0 (1 - q^n)$	$T'_1 (1 - q^{n-1})$	$T'_2 (1 - q^{n-2})$	...	...	$T'_{n-1} (1 - q)$	T'

This gives the final temperature in terms of the readings, and is often useful when the run has not been continued quite long enough to reach a steady condition. Of course it should not be employed when the temperatures are far from constant, unless outside conditions are far steadier than they ever are in practice.

It now remains to give a few examples illustrating the above methods. A certain railway motor gave, as the mean temperature of the field-coils, the following readings at hourly intervals:—

$$57{\cdot}5^\circ,\ 64^\circ,\ 68{\cdot}2^\circ,\ 71^\circ\ \mathrm{C.};$$

thus from the first three—

$$q = \frac{4{\cdot}2}{6{\cdot}5} = {\cdot}645;$$

and from the last three—

$$q = \frac{2{\cdot}8}{4{\cdot}2} = {\cdot}665.$$

Thus we may take $q = {\cdot}65$, leading to $p = {\cdot}43$. Had the readings been taken half-hourly, we should have had—

$$q = \sqrt{{\cdot}65},\ p = \frac{1}{2} \times {\cdot}43.$$

The final temperature indicated by the above is—

$$\theta = 71 + \frac{2{\cdot}8^2}{1{\cdot}4} = 76{\cdot}6^\circ\ \mathrm{C.}$$

In one of the runs on these motors, the mean voltages found for the last six hours of the run were as follows:—

526, 535, 518, 492, 488, 506.

Thus, from equation (10)—

$$V'(1 - {\cdot}65^6) = 506 - 18 \times {\cdot}65 + 4 \times {\cdot}65^2 + 26 \times {\cdot}65^3 + 17 \times {\cdot}65^4 - 9 \times {\cdot}65^5 - 526 \times {\cdot}65^6,$$

or

$$V' = 503 \text{ volts.}$$

The time that the regular schedule was stopped for taking temperatures was, for the several hours, 6 min., 4 min., 4 min., 8 min., 5 min., 6 min., 4 min. As these intervals of time occur at the ends of the hours, we shall divide each equally between the hours that they end and begin, and thus we get the series, 5 min., 4 min., 6 min., 6·5 min., 5·5 min., 5 min. Thus the equivalent time lost is from equation (11)—

$$t' = 5{\cdot}4 \text{ minutes.}$$

The readings of air temperature were respectively, 27·5°, 29°, 32°, 30·5°*, 29°, 27°, 20·5° C.

* Reading omitted and supplied by interpolation.

Thus, from equation (12)—

$$T'(1 - \cdot 65^6) = \frac{1}{2}\Big\{20\cdot 5 + 27 + 8\cdot 5 \times \cdot 65 + 3\cdot 5 \times \cdot 65^2 + 3 \times \cdot 65^3 - 1\cdot 5 \times \cdot 65^4 - 4\cdot 5 \times \cdot 65^5 - (27\cdot 5 + 29) \times \cdot 65^6\Big\}$$

or

$$T' = 27\cdot 2^\circ \text{ C.}$$

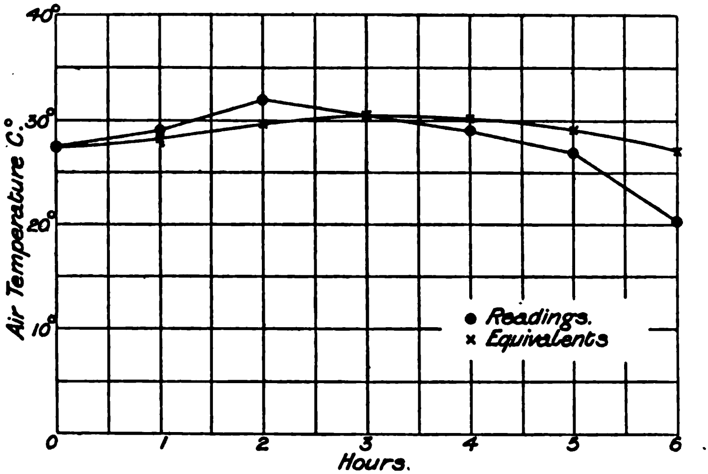


FIG. 1.

Calculating T′ for each hour from equation 13, according to the method given in the table on page 1111, we get the following:—

	20·5	27	29	30·5	32	29	27·5
	6·5	2	1·5	1·5	− 3	−1·5	27·5
·65	−2·92	− ·32	0	−2·92	·98	·98	17·88
·423	− ·21	0	−1·90	·64	·64		11·65
·275	0	−1·24	·42	·42			7·58
·178	− ·81	·27	·27				4·94
·116	·18	·18					3·21
·075	·12						2·09
	2·86	·89	·29	− ·36	−1·38	− ·52	
÷ ·43 =	6·64	2·07	·67	− ·84	−3·21	−1·21	
$T_0 - q^n T_n$	18·41	23·79	24·06	22·92	20·35	11·12	27·5
	25·05	25·86	24·73	22·08	17·14	9·91	
T′ =	27·1	29·2	30·1	30·5	29·7	28·4	27·5

In Fig. 1 the readings of air temperature and the calculated equivalent temperature are plotted, and the curves show how sluggish such a machine may be in responding to a change of outside conditions.

Thus, we see how the indefiniteness in the results due to varying outside conditions can, to a very great extent, be removed by keeping a careful record of outside conditions, and computing from the record certain fictitious constant conditions, equivalent to the actual conditions in thermal effect. By such means this very troublesome type of test can be made to yield results whose consistency is in keeping with their importance, and that with comparatively small labour.

At a Special General Meeting of Members, Associate Members, and Associates duly convened and held at the Offices of the Institution, 92, Victoria Street, Westminster, on Friday, July 31, 1903—Mr. ROBERT K. GRAY in the chair.

The Secretary read the notice convening the Meeting.

The President explained that the Council considered it would be unwise not to take advantage of an opportunity which offered to acquire certain property in Tothill Street, although they did not propose to proceed immediately with the construction of the building.*

He therefore proposed—

> "That the purchase of the property in Tothill Street at the price of £16,500 be sanctioned and approved, and that the sale of such of the investments of the Institution as the Council may select as may be necessary to provide the purchase money be sanctioned."

The resolution was seconded by Mr. W. M. Mordey, and was then put to the meeting and carried.

The President having declared the resolution carried, proposed a vote of thanks to the Building Committee, which was also carried.

* The property, which is in part freehold, in part long leasehold (over 900 years), is at present tenanted and yields a return for the invested capital.

The Thirty-first Annual General Meeting of the Institution was held at the Offices of the Institution, 92, Victoria Street, S. W., on Thursday afternoon, May 28th, 1903, at 5 p.m.—Mr. ROBERT KAYE GRAY, President, in the chair.

The Secretary read the notice convening the Meeting.

The minutes of the Ordinary General Meeting of May 12th were, by permission of the meeting, taken as read, and signed by the President.

The names of new candidates for election, after having been suspended, previous to the meeting, in the Library, were taken as read, and the President stated that, the present meeting being the last of the Session, the candidates would, as usual, be balloted for that afternoon.

The following list of transfers was published as having been approved by the Council :—

From the class of Associate Members to that of Members—

Arthur Pemberton Wood.

From the class of Associates to that of Members—

Henry Cuthbert Hall.

From the class of Associates to that of Associate Members—

Jas. Lowry Chambers.
Sidney Crouch.
Wm. Densham.
Sorab Frommurze.
Philip Hunter-Brown.
Christopher Holden.
Victor Martos.
Evers Musgrave.
Geo. Addison Williams.
Herbert Wm. Wilson.

Messrs. W. McGregor and E. O. Walker were appointed scrutineers of the ballot for new members.

Donations were announced as having been received since the last meeting, to the *Library* from Messrs. J. J. Fahie, and Rentell & Co.; to the *Building Fund* from Messrs. W. R. Rawlings, R. Rigg, Captain Saltren-Willett; and to the *Benevolent Fund* from Captain Saltren-Willett, to all of whom the thanks of the meeting were unanimously accorded.

The PRESIDENT: The next matter before us is the Annual Report of the Council. I believe that all those present have the Report in their hands, and I think I should meet the convenience of every one by asking you to take the Report as read. If any one objects to that proceeding I shall be very glad to do otherwise, but it is a lengthy document. Is it your pleasure that it should be taken as read?

The motion was carried *nem. con.*

REPORT OF THE COUNCIL PRESENTED AT THE ANNUAL GENERAL MEETING OF MAY 28, 1903.

The Council has the pleasure of presenting its Annual Report upon the work of the Institution.

THE ARTICLES OF ASSOCIATION.

The rapidly extending scope and work of the Institution had for some years past been attended by an increase in expenditure greater in proportion than the growth of revenue, and the Council considered that to place the Institution finances upon a sound basis, some alteration in the rates of subscription would have to be faced. A letter was therefore sent to the members of all classes explaining the proposals of the Council, and freely inviting expressions of opinion.

The Council was gratified at the response to their invitation. The replies were analysed, and all the views expressed in them carefully considered, with the result that the original proposals were modified in some respects. The final proposals to alter the subscriptions were laid before the necessary Special General Meetings of Members on the 4th and 19th of December, 1902. The opportunity was taken to put forward certain alterations in others of the Articles of Association. Yet further proposals that were not in shape at the time of these meetings, which had of necessity to be held before the commencement of the new subscription year, were laid before Special General Meetings of Members on the 26th of February and the 17th of March, 1903.

The proposed alterations were duly made, and now appear in the Journal of the Institution. Apart from the alterations of subscriptions the following changes among others have been effected :—

The raising of the normal age for admission to the class of Members (M.I.E.E.) from twenty-five to thirty ;

The suppression of the special clause under which Associates on the Register in 1898 could apply for transfer to the class of Associate Members without being proposed and supported by Members of the Institution ;

The cessation of entries to the class of Foreign Members, a class which was in some sense redundant, since foreigners, equally with British subjects, are eligible for admission to any class for which they may be, professionally and otherwise, qualified ;

The increase in the upper age limit, from twenty-two to twenty-six, of Students who have been three years or over attached to the Institution, so that qualified Students pass direct to the class of Associate Members, whilst a sub-class of Senior Students has been created with a subscription intermediate between that of a Junior Student and that of an Associate ;

The conferment on the Council of power, to be used at their discretion, to remove from the Register the name of any convicted felon or, if need be, of an adjudicated bankrupt ;

The restriction of the field of selection of a President to past and present Vice-Presidents, and of that of a Vice-President to past and present Members of Council ; and the retirement of two Vice-Presidents

(instead of one) annually, in order to increase the number of candidates eligible for the office of President; and

The extension to Associate Members of the privilege of attending and voting at meetings called to alter the Articles of Association.

The Presidency.

During the Session, the arrangement for the entertainment of the Delegates to the International Telegraph Conference, and the desire on the part of Mr. Swinburne that these arrangements should, from the outset, be made by a direct representative of some branch of Telegraphy, led to his placing his resignation of office in the hands of the Council two months earlier than he would ordinarily have retired. The Council reluctantly accepted his decision, and expressed in the following Resolution its feelings of gratitude for the good work that he had done for the Institution while President, and its regret that his term of office should have been shortened:—

"Resolved that the Council, in placing on record its high appreciation of Mr. Swinburne's generosity in vacating the Presidential chair before his year of office had expired in order to assist the Council in making adequate arrangements for the reception of the delegates to the approaching International Telegraph Conference, desires hereby to express its cordial thanks to Mr. Swinburne for the admirable way in which he has conducted the affairs of the Institution during his Presidency, and for the unfailing tact and courtesy which he has shown throughout."

Mr. Robert Kaye Gray was unanimously elected President in place of Mr. Swinburne.

The Treasurership.

It was with great regret that the Council, in October, received from Professor Ayrton his resignation of the office of Treasurer, as foreshadowed by him at the last Annual General Meeting. The Council felt that they were losing the services of one who, unsparing of himself, had given unstinted help to the Institution for many years, and they regretted his resignation the more because it was largely due to ill-health. They are glad, however, to feel that his personal interest in the work of the Institution is unabated.

In his place the Council elected Mr. Robert Hammond, who for some years had been an active and valued member of the Finance Committee.

Local Sections.

During the year a Local Section has been formed with its centre at Leeds, embracing the whole of Yorkshire with the exception of Middlesbrough and the Cleveland District, which were already included in the area of the Newcastle Local Section.

The good work of the older Local Sections has gone on steadily, and the Council offers its warmest congratulations to the several Com-

mittees and their respective Hon. Secretaries for the able management of their affairs.

Elections and Transfers.

During the period since the last Annual General Meeting there have been elected 35 Members, 135 Associate Members, 155 Associates, and 229 Students, making a total of 554. 58 Candidates have also been approved for ballot to-night.

Twenty-three Associate Members, 2 Foreign Members, and 14 Associates have been transferred to the class of Members; 213 Associates and 3 Students have been transferred to the class of Associate Members, and 61 Students to the class of Associates.

Deaths and Resignations.

The Council mourns the loss to the Institution by death of 1 *Past President*, Sir Frederick A. Abel, Bart; 8 *Members*, F. Bolton, E. T. Carter, F. T. B. Daniell, Dr. J. H. Gladstone, H. T. Goodenough, A. Graves, G. R. Mockridge, S. H. Short, C. F. Tietgen, J. Wimshurst; 6 *Associate Members*, F. Bathurst, B. A. Giuseppi, L. W. Heath, M. G. A. Humphrey-Moore, J. Seccombe, C. G. Vines; 8 *Associates*, G. H. Bailey, J. Beattie, A. Dennis, W. H. Druce, H. D. Fearon, R. Gibson, F. B. Hobler, G. Ireland, A. D. Manlove; and 1 *Student*, J. Walker-Hanna.

Fourteen Members, 3 Associate Members, 16 Foreign Members, 52 Associates, and 12 Students have resigned since the date of the last Report.

Trustee.

By the death of Sir Frederick Abel, the Institution has lost one of its oldest Trustees. In his place Mr. James Swinburne has been appointed a Trustee of the Institution, and also of the Willans Fund.

Papers.

In addition to the President's Inaugural Address, the following papers, read at Ordinary and Extraordinary General Meetings, will be found in Volume 32 of the Journal :—

Date. 1902.	Title of Paper.	Name of Author.
Nov. 27.—	"On Electrons"	Sir O. Lodge, F.R.S., Vice-President.
Dec. 11.—	"Photometry of Electric Lamps"	Dr. J. A. Fleming, F.R.S.
1903.		
Jan. 8.—	"Notes on Recent Electrical Design"	W. B. Esson, Member.
„ 8.—	"Notes on the Manufacture of Large Dynamos and Motors"	E. K. Scott, Member.
„ 22.—	"Notes on the Metrical System of Weights and Measures"	A. Siemens, Past President.
Feb. 12.—	"The Nernst Lamp"	J. Stöttner, Member.
Mar. 26.—	"Distribution Losses in Electric Supply Systems"	A. D. Constable, Associate Member; E. Fawssett, Associate.

Date. 1903.	Title of Paper.	Name of Author.
April 30.	—"Divided Multiple Switchboards, an Efficient Telephone System for the World's Capitals"	W. AITKEN, Member.
May 7.	—"Applications of Electricity in Engineering and Shipbuilding Works"	A. D. WILLIAMSON, Member.
„ 7.	—Electric Driving in Machine Shops"	A. B. CHATWOOD, Member.

And the following papers, selected from those read at Local Section Meetings, have been (up to the present) accepted for publication :—

BIRMINGHAM LOCAL SECTION.

Date.	Title.	Author.
1902.		
Mar. 19.	—"Tests on the Nernst Lamp"	R. H. HULSE.
Dec. 10.	—Chairman's Inaugural Address	H. LEA, Member.
1903.		
Feb. 25.	—"Network Tests and Station Earthing"	A. M. TAYLOR, Member.
April 29.	—"Notes on Motor Starting Switches"	A. H. BATE, Associate Member.

DUBLIN LOCAL SECTION.

May 29.	—"Lighting and Driving of Textile Mills by Electricity"	M. OSBORNE, Associate Member.
Nov. 21.	—"A Hydro-Electric Phenomenon"	F. GILL, Member.

GLASGOW LOCAL SECTION.

April 8.	—"Notes on the Testing of Tramway Motors, and an Investigation into their Characteristic Properties"	M. B. FIELD, Member.
Nov. 11.	—"The Design of Continuous Current Dynamos"	H. A. MAVOR, Member.
1903.		
Feb. 10.	—"A Study of the Phenomenon of Resonance in Electric Circuits by the Aid of Oscillograms"	M. B. FIELD, Member.*

MANCHESTER LOCAL SECTION.

1902.		
Nov. 25.	—"High Temperature Electro-Chemistry: Notes on Experimental and Technical Electric Furnaces"	R. S. HUTTON, Associate; and J. E. PETAVEL, Associate Member.
1903.		
Jan. 20.	—Chairman's Inaugural Address	H. A. EARLE, Member.
Mar. 3.	—"The Arrangement and Control of Long Distance Transmission Lines"	E. W. COWAN and L. ANDREWS, Members.
April 7.	—"Comparison between Steam and Electrically Driven Auxiliary Plant in Central Stations"	C. D. TAITE, Member, and R. S. DOWNE, Associate Member.
„ 21st	—"The Carriage of Goods on Electric Tramways"	A. H. GIBBINGS, Member.

LEEDS LOCAL SECTION.

Feb. 19.	—Chairman's Inaugural Address	H. DICKINSON, Member.
„ 19.	—"Motive Power Supply from Central Stations"	R. A. CHATTOCK, Member
Mar. 19.	—"Electricity Supply for Small Towns and Villages"	A. B. MOUNTAIN, Member.

* This paper was afterwards read in Abstract, and discussed with Messrs. Constable and Fawssett's paper, at an Ordinary General Meeting of the Institution in London.

NEWCASTLE LOCAL SECTION.

DATE.	TITLE.	AUTHOR.
1902.		
Feb. 17.—	"The Equipment of a Modern Telephone Exchange"	F.A. S. WORMULL, Associate.
Nov. 17.—	Chairman's Inaugural Address	J. H. HOLMES, Member.
Dec. 1.—	"Experiments on Synchronous Converters"	Dr. W. M. THORNTON, Member.
„ 15.—	"Railway Block Signalling"	J PIGG, Associate Member.
1903.		
Jan. 19.—	"Methods of Supporting and Protecting Inside Conductors"..	O. L. FALCONAR, Associate Member.
Feb. 16.—	"Some Notes on Continental Power-House Equipment"..	H. L. RISELEY, Associate Member

The Institution is again indebted to the Institution of Civil Engineers, and to the Society of Arts for the permission to hold the General Meetings of the Institution in their rooms.

PUBLICATIONS OF THE INSTITUTION.

The papers above referred to have been, or will be, printed in the Journal of the Institution, and, in addition, the following Original Communications have been approved for publication :—

"Notes on the Teaching of Electrical Engineering in the Technical High Schools of Charlottenburg and Darmstadt"	D. K. MORRIS, Associate Member.
"Mean Horizontal and Mean Spherical Candle-Power..	A. RUSSELL, Member.

SCIENCE ABSTRACTS.

The publication of *Science Abstracts* in collaboration with the Physical Society is continued, and Mr. J. E. Kingsbury has been added to the Committee as a representative of the Institution in place of Mr. W. R. Cooper, who, having been elected an Hon. Secretary of the Physical Society, is now an *ex-officio* member.

The Council notes with pleasure that the American Physical Society has identified itself with *Science Abstracts*, and that it is represented on the Committee by Professor E. H. Hall ; and, further, that the American Institute of Electrical Engineers is giving direct assistance in the work.

Having in view the increase in the quantity and scope of the matter to be abstracted, it appeared desirable to the Committee to divide the Abstracts into two Sections, one to be devoted to Physics and the other to Engineering, and with the sanction of the constituent Societies this was done at the commencement of the present year. At the same time it was seen that the arrangement under which the publication had hitherto been conducted could no longer be continued unchanged. A new basis of agreement was therefore adopted, under which the Institution and the Physical Society contribute certain fixed sums towards the General Expenses of publication, and a further payment for each copy supplied to its members. The gratuitous distribution of the Abstracts by the Institution was stopped as from

January 1st, and a small charge was levied upon each member requiring a copy. In this way the Council feels that the Institution is able to give the necessary assistance to a valuable publication without incurring very heavy charges for the supply of copies of the publication to those members who may not wish to receive it.

The sum of £920 shown in the accompanying Statement of Accounts as a contribution to *Science Abstracts* is the last annual payment under the old *régime;* the amount to be contributed in 1903 will be very much reduced.

Wiring Rules and Model General Conditions.

The Wiring Rules of the Institution have now been published, and have received the adhesion of the Council of the Incorporated Municipal Electrical Association. They have also been adopted by a number of supply undertakers and insurance offices.

A standing Committee has been appointed by the Council to consider all questions of revision, so that the rules may from time to time be amended and kept up to date.

The set of Model General Conditions drawn up by a special representative Committee has now also been published, and has been received favourably.

The Council earnestly hopes that the long and careful work expended in the preparation of the Wiring Rules and of the Model General Conditions will prove to be of great benefit to the Electrical industry.

Annual Premiums.

The Council has awarded the following premiums for papers and communications :—

The Institution Premium, value £25,

to Dr. J. A. Fleming, F.R.S., for his paper entitled "Photometry of Electric Lamps";

The Paris Electrical Exhibition Premium, value £10,

to Mr. M. B. Field, for his paper entitled "A Study of the Phenomenon of Resonance in Electric Circuits by the Aid of Oscillograms";

Two Extra Premiums, value £10 each,

one to Messrs. A. D. Constable and E. Fawssett jointly, for their paper entitled "Distribution Losses in Electric Supply Systems"; and the other to Dr. W. M. Thornton, for his paper entitled "Experiments on Synchronous Converters";

An Original Communication Premium, value £10,

to Messrs. A. Russell and C. C. Paterson, for their communication entitled "Sparking in Switches."

STUDENTS' PREMIUMS.

A premium, value £7, to J. GRIFFIN, for his paper on "Synchronous Electrical Machinery."

A premium, value £5, to F. J. HISS, for his paper on "An Analysis of some Points in Three-phase Motor Design."

A premium, value £5, to E. FISHER, for his paper on "Three-wire System of Electric Lighting by Continuous Current."

A premium, value £4, to A. G. ELLIS, for his paper on "The Paralleling of Alternators."

A premium, value £3, to T. H. VIGOR, for his paper on "The Photometry of Electric Lamps."

In accordance with precedent, the Council in making the awards of premiums has not taken into account the papers contributed by present members of the Council. Papers other than those of the Students' Section, which were not in type by the end of April, 1903, were reserved for consideration in awarding premiums in 1904; but certain papers which were received too late for consideration in 1902 have been taken into account this year.

SALOMONS SCHOLARSHIP.

The Council has awarded Salomons Scholarships, value £50 each, to Mr. G. B. DYKE, of University College, London; and to Mr. H. W. KEFFORD, of the Central Technical College.

DAVID HUGHES SCHOLARSHIP.

The award of the David Hughes Scholarship, value £50, has this year been made to Mr. W. H. WILSON, of King's College, London.

STUDENTS' CLASS.

Twelve meetings of the Students' Class have been held during the Session, at which papers have been read and discussed, and the work of the Section progresses steadily. Visits to the following places have been arranged during the Session :—

1902.

Nov. 27.—The Works of Messrs. Siemens' Bros. & Co., Limited, Woolwich, S.E.

Dec. 6.—The Works of the Central London Railway, Shepherd's Bush, W.

1903.

Jan. 17.—The Works of the India Rubber, Gutta Percha, and Telegraph Works Company, Silvertown, E.

„ 31.—The Joint Works of the Notting Hill and Kensington Electricity Supply Companies, Ltd., Shepherd's Bush, W.

Feb. 7.—The Works of Messrs. Johnson & Phillips, Charlton, S.E.
„ 13.—The Works of the Electrical Power Storage Company, Limited, Millwall, E.
„ 20.—The Board of Trade Laboratory, Whitehall, S.W.
„ 27.— „ „ „
March 7.—The Works of the London United Tramways, Limited.
„ 12.—The Works of the Incandescent Electric Lamp Company, Limited, Hammersmith, W.
„ 28.—The Telephone Exchange of the General Post Office.
April 4.—The Islington Electricity Supply Works.
May 2.—The Works of the Western Electric Company.
„ 16.—The Works of Messrs. Elliott Bros., Lewisham.

During the Easter holidays a visit has been paid to the following Works in the neighbourhood of Manchester and Sheffield, in an excursion successfully organised by the Students' Committee, which has been fortunate in receiving the continued assistance of Mr. H. D. Symons as Hon. Secretary :—

Messrs. E. Allen & Co.
Messrs. Askham, Bros. & Wilson.
Messrs. John Brown & Co., Limited.
The British Westinghouse Electric Manufacturing Company, Ltd.
The Chloride Electrical Storage Company, Limited.
Messrs. Cooke & Co.
Messrs. S. Z. de Ferranti, Limited.
The Manchester Corporation Electricity Works.
The Nunnery Colliery Company.
The Sheffield Corporation Electricity Works.
The Sheffield Corporation Tramways Generating Station.
Messrs. Walker & Hall.

The Council records its thanks to the owners and managers of the several works, both in and around London, and in Sheffield and Manchester, for their assistance to the Students in thus throwing open their works to inspection.

Annual Dinner.

The Annual Dinner was held in the Grand Hall of the Hotel Cecil on the 17th of December, the company numbering about 326; an early adjournment was made to the adjacent Victoria Hall for conversation, and it is believed that the innovation was greatly appreciated.

Annual Conversazione.

The Annual Conversazione, held on the 1st of July at the Natural History Museum, gave the Institution the privilege of welcoming not only the members of the Incorporated Municipal Electrical Association, which was holding its Annual Convention in London at the time, but the Delegates to the International Tramways and Light Railways Congress, which was also in session in the capital during that week.

Annual Accounts and Financial Position.

The large increase in membership during the year, and the absence of unusual calls for expenditure, have allowed a substantial sum to be invested.

In the Annual Statement of Accounts, appended hereto, a slight change has been made in order to show clearly the financial result of the year's working, thus making it possible in future years to compare readily the results with those of former years. It will be seen that credit has been taken on the income side for that amount of arrears of subscriptions which, from the experience of former years, is estimated as being recoverable. On the other hand, sums received as entrance fees being considered rather as additions to capital than as income, have been carried direct to Capital Account. In conformity with modern usage the Income and Expenditure sides of the Statement of Accounts have been interchanged.

In the Balance Sheet for 1901, a sum of £90 9s. 6d. appears as representing the value of the Stock of Institution Journals, Ronalds Library Catalogues, etc., and a sum of £18 15s. 2d. as representing that of Cooke Manuscripts, on the 31st of December of that year. The value of old stock of Journals and publications being difficult to assess, it has been decided to discontinue the practice of including this stock as an Asset.

As the amount received in 1902 in respect of sales of the Institution Journal amounted, after deducting the cost of advertising, to £182 7s. 6d., the value (£108 14s. 8d.) of the stock of Journals and Cooke Manuscripts, as given in the last Balance Sheet, has been deducted from this sum, and the difference, £73 12s. 10d., appears on the creditor side of the Statement of Income and Expenditure for 1902, as the net proceeds of the sale of the Journal last year. The entries, "Stock of Institution Journals, Ronalds Library Catalogues, etc.," and "Stock of Cooke Manuscripts," cease therefore to appear in the Balance Sheet; and, in future, the proceeds from sales of Journals will appear as revenue.

Building Fund.

The Building Fund, which at the commencement of the year 1902 stood at £9,397 18s. 9d., was, on the 31st of December, £10,691 1s. 11d. The increase included a sum of £800 transferred from the surplus income, and a sum of £15 presented by the Engineering Society of the Finsbury Technical College.

The Council has to express its satisfaction at having also received during the later portion of the Session a donation of £76 19s. from 637 Students of the Institution. This amount was collected and forwarded spontaneously by the Committee of the Students' Section; for the work involved, the Council is grateful to the Committee, and especially to the Hon. Secretary of the Section, Mr. H. D. Symons. The Council particularly appreciates the spirit in which the gift was made to the Building Fund, and the evidence that it affords of the attachment of the younger members to the Institution.

The Institution Benevolent Fund.

At the request of the contributors to the Benevolent Fund, the management has now been transferred to a Committee consisting of the President and six members of the Council, with three contributors to the Fund who are not for the time being members of Council. This Committee is in the appointment of the Council.

The Wilde Benevolent Fund.

No grant has been made from this Fund during the year.

Local Honorary Secretaries.

During the past Session, Mr. R. H. Krause has retired from the office of Local Honorary Secretary and Treasurer for Austria-Hungary, owing to his change of residence, and Herr A. Von Boschan has been appointed in his place.

Mr. John Hesketh has succeeded Mr. R. O. Bourne as Local Honorary Secretary and Treasurer for Queensland, on the appointment of the latter as Commonwealth Public Service Inspector; and Mr. James Oldham is now Local Honorary Secretary and Treasurer for Uruguay in place of his brother, Mr. John Oldham.

Mr. W. Grigor Taylor, on leaving the East, has been obliged to give up his office of Local Honorary Secretary and Treasurer for the Straits Settlements.

To all of these retiring Officers the Council desires to convey its hearty thanks and its acknowledgment of the good services rendered by them to the Institution; and to those newly elected it expresses its gratification that they have undertaken to assist the Institution in their several districts.

At the suggestion of Mr. H. H. Kingsford, the Secretariat for Peru and Mexico has been divided, Mr. Kingsford retaining the office of Local Honorary Secretary and Treasurer for Peru. No appointment has yet been made to the Mexican Secretariat.

Visit of the Institution to Italy.

Immediately before Easter, 1903, a party of 117 members and others, and 27 ladies, visited the electrical works and railways of Northern Italy.

Arriving in Como on the 3rd of April, they visited the Valtellina Railway, and on the 6th of April continued their journey to Milan, whence they visited the Milan-Varese Electric Railway and the Power Stations at Paderno, Vizzola, and Tornavento, and the following works in and around Milan :—

The Porta Volta and S. Radagonda Stations of the Italian Edison Co.
Messrs. Gadda & Co. and Brioschi Finzi & Co.
Officine Meccaniche.
Messrs. Pirelli & Co.
Messrs. Riva, Monneret & Co.

The Milan Telephone Exchange of the Società Telefonica per l' alta Italia.
Messrs. Franco Tosi.
Messrs. Gavazzi & Co.
Messrs. Frua and Banfi.

While at Como, an opportunity was taken to arrange for a corporate visit to the tomb of Alessandro Volta; a wreath was laid upon the tomb by the President in the name of the Institution, and a bronze shield with a suitable inscription, subscribed for by the Students' Section, was presented by Mr. J. R. Hewett, acting on their behalf.

The Council desires to express its deep indebtedness to Professor Ascoli and the Associazione Elettrotecnica Italiana, and specially to Signor A. Bertini, the President, and Signor G. Semenza, the Secretary of the Milan Section of the Association, to the Mayors and Councils of Como and Camnago Volta, and to the Adriatic and Mediterranean Railway Companies, the Italian Edison Company, the Società Lombarda per Distribuzione di Energia Elettrica, the Compagnie Thomson Houston de la Méditerranée, to the firms mentioned above, and to the many other firms and individuals who in various ways contributed to the very hearty welcome, which was greatly appreciated by the visitors.

The warmth of the reception and the generous hospitality of the Italian hosts will live in the memory of all who were fortunate enough to be of the party.

Departing from previous practice, the Institution, without accepting corporate responsibility, undertook the management of the arrangements for railway and hotel accommodation for those of the number who were not inclined to make their own dispositions. All the expenses connected with the excursions were borne by those availing themselves of the accommodation provided. This plan proved very successful, owing to the tireless energy of Mr. McMillan, the Secretary, and to the devotion of the staff.

Visit to America in 1904.

The Council has received and accepted an invitation from the American Institute of Electrical Engineers to visit the United States in 1904. The McGill University, of Montreal, has invited the two Institutions to hold a joint meeting in their building at this time. The invitations, both from the American Institute and from the McGill University, are couched in the most cordial terms, and the Council hopes that it may be possible to arrange not only for a visit to the Eastern States of America and to the St. Louis Exhibition, but also for the proposed joint meeting in Canada.

The Factories and Workshops Acts, 1901.

The Institution has been in close touch with the Home Office in regard to the provisions of the Factory Act with reference to the employment of "young persons" under the age of eighteen in electricity works; and the Home Secretary has now made such provisions

as are in his power to allow of the employment of such young persons under suitable conditions. The Council is indebted to the Home Secretary for having received the representations voiced by the Institution in deference to the request of the Conference referred to in the last Report.

It is understood that no special regulations for electricity works under the Factories and Workshops Act will be made without an opportunity being first given to the industry to consider them, and, if necessary, to make representations to the Home Office with reference to them.

Parliamentary and Industrial Committee.

A Parliamentary and Industrial Committee has been appointed by the Council. "To collect information, consider, and report to the Council on proposed legislation, regulations, enactments, and policy, so far as they may be expected to affect Electrical Industries generally from the Engineering point of view; and to make recommendations to the Council as to the advisability of taking action thereon, or otherwise."

Code of Professional Etiquette.

A Committee was appointed by the Council to inquire whether any steps should be taken with regard to the question of professional etiquette. This Committee drew up a code of etiquette which, after consideration, was adopted and published by the Council during the year 1902, with the object of making generally known the views of the Council on this difficult subject.

National Physical Laboratory.

Professor Ayrton's period of office as a representative of the Institution on the General Board of the National Physical Laboratory having expired, and he being ineligible for re-appointment, Mr. Robert Kaye Gray has been nominated by the Council to serve in his stead.

Engineering Standards Committee.

The work of this Committee, in which this Institution is associated with the Institution of Civil Engineers, the Institution of Mechanical Engineers, the Institution of Naval Architects, and the Iron and Steel Institute, is progressing steadily. This Institution has contributed £250, and the Council learns with pleasure that a grant of £3,000 has been made by Government, towards the expenses of the present year.

Work of the Institution.

The work of the Institution continues steadily to increase, both in amount and importance. During the past year there have been 21 Committees at work. 16 General Meetings, 4 Special General Meetings of Members, 26 Council Meetings, and 93 Committee Meetings have been held.

NEW OFFICES.

The Members of Council have long had before them the fact that the accommodation afforded by the offices in which the Institution has had its home for the last thirteen years had become inadequate. Feeling that the time had arrived when a change should be made, it was decided to move to 92, Victoria Street, Westminster, where the conditions of light and space are more in accordance with the needs of the Institution. The increased accommodation will permit of the Library being rearranged and considerably enlarged. The removal was effected in March without any serious dislocation of business.

THE CORONATION OF THEIR MAJESTIES KING EDWARD VII. AND QUEEN ALEXANDRA.

It will be remembered that on the occasion of the Annual Conversazione last year, when His Majesty the King was lying dangerously ill, a special resolution was passed at that gathering, and that this resolution received a gracious acknowledgement from Her Majesty the Queen. Fortunately a few weeks later the Institution was able to submit a loyal and dutiful Address in connection with the Coronation.

THE LIBRARY.

Report of the Secretary.

I have to report that the accessions to the Library during the twelve months, from May 15th, 1902, to the date of the Annual General Meeting, numbered 90; nearly all of these were kindly presented by the authors or publishers.

The supply of specifications of electrical patents and that of abridgments of specifications relating to electricity and magnetism are continued by the kindness of H.M. Commissioners of Patents, and the arrangement is still in force whereby the specifications of all electrical patents published during any week are placed on the Library table on the following Monday morning.

The periodicals or printed proceedings of other societies received regularly are, with some additions, the same as last year, as may be seen by the list appended hereto.

The number of visitors to the Library in the twelve months from May 23rd, 1902, to the date of the Annual General Meeting, has been 366, of whom 17 were non-members.

By order of the Council the Library was closed for a fortnight during March, at the time of the removal into the new rooms of the Institution.

WALTER G. McMILLAN, *Secretary.*

APPENDIX TO SECRETARY'S REPORT.

TRANSACTIONS, PROCEEDINGS, &c., RECEIVED BY THE INSTITUTION.

BRITISH.

Asiatic Society of Bengal, Journal and Proceedings.
Cambridge Philosophical Society.
Engineering Association of New South Wales.
Greenwich Magnetical and Meteorological Observations.
Institute of Patent Agents, Transactions.
Institution of Civil Engineers, Proceedings.
Institution of Mechanical Engineers, Proceedings.
Iron and Steel Institute, Proceedings.
King's College Calendar.
Liverpool Engineering Society, Proceedings.
Municipal Electrical Association, Proceedings.
National Physical Laboratory Report.
North of England Institute of Mining and Mechanical Engineers Transactions.
Physical Society, Proceedings.
Royal Dublin Society, Transactions and Proceedings.
Royal Engineers' Institute, Proceedings.
Royal Institution, Proceedings.
Royal Meteorological Society, Proceedings.
Royal Scottish Society of Arts, Transactions.
Royal Society, Proceedings.
Royal United Service Institution, Proceedings.
Society of Arts, Journal.
Society of Chemical Industry, Journal.
Society of Engineers, Proceedings.
Surveyors Institution, Transactions.
University College Calendar.

AMERICAN AND CANADIAN.

American Academy of Science and Arts, Proceedings
American Institute of Electrical Engineers, Transactions.
American Philosophical Society, Proceedings.
American Society of Mechanical Engineers, Transactions.
Canadian Society of Civil Engineers, Transactions.
Cornell University, Library Bulletin.
Engineers' Club of Philadelphia, Proceedings.
Franklin Institute, Journal.
John Hopkins University, Circulars.
Nova Scotia Institute of Science, Proceedings.
Ordnance Department of the United States, Notes.
Western Society of Engineers, Journal.

BELGIAN.

Association des Ingénieurs Électriciens sortis de l'Institut Electro-Technique Montefiore, Bulletin.
.Société Belge d'Électriciens, Bulletin.

DANISH.

Tekniske Forening, Tidsskrift.

DUTCH.

Koninklijk Institut van Ingenieurs, Tijdschrift.

FRENCH.

Académie des Sciences, Comptes Rendus Hebdomadaires des Séances.
Association Amicale des Ingénieurs-Électriciens, Bulletin Mensuel.
Société Française de Physique, Bulletin des Séances.
Société des Ingénieurs Civils, Mémoires.
Société Internationale des Électriciens, Bulletin.
Société Scientifique Industrielle de Marseille, Bulletin.

GERMAN.

Verein Deutscher Ingenieure, Zeitschrift.
Verein zur Beförderung des Gewerbfleisses, Verhandlungen.

ITALIAN.

Associazione Elettrotecnica Italiana, Atti.

RUSSIA.

Section Moscovite de la Société Impériale Technique Russe.

LIST OF PERIODICALS RECEIVED BY THE INSTITUTION.

BRITISH.

Cassier's Magazine.
Electrical Engineer.
Electrical Review.
Electrical Times.
Electrician.
Electricity.
Electro-Chemist and Metallurgist.
Engineer.
Engineering.
Engineering Times.
English Mechanic and World of Science.
Feilden's Magazine.
Illustrated Official Journal, Patents.
Indian and Eastern Engineer.
Invention.

Light Railway and Tramway Journal.
Mechanical Engineer.
Nature.
Page's Magazine.
Philosophical Magazine.
Scottish Electrician.

AMERICAN.

American Electrician.
Electrical Review.
Electrical World and Electrical Engineer.
Electricity.
Engineering News.
Journal of the Telegraph.
Physical Review.
Scientific American.
Street Railway Journal.
Technology Quarterly.
Western Electrician.

AUSTRIAN.

Zeitschrift für Elektrotechnik.

DUTCH.

De Ingenieur.

FRENCH.

Annales Télégraphiques.
L'Éclairage Électrique.
L'Électricien.
L'Industrie Électrique.
Journal de Physique.
Journal Télégraphique.
Le Mois Scientifique et Industriel.

GERMAN.

Annalen der Physik und Chemie.
Beiblätter zu den Annalen der Physik und Chemie.
Centralblatt für Accumulatoren und Elementenkunde.
Electrotechnischer Anzeiger.
Electrotechnische Zeitschrift.
Zeitschrift für Elektrochemie.
Zeitschrift für Instrumentenkunde.

ITALIAN.

L'Elettricità.
Giornale del Genio Civile.
Il Nuovo Cemento.

SPANISH.

La Ingenieria.

The Institution of

STATEMENT OF INCOME AND
ENDING 31st

Dr.

EXPENDITURE.

	£	s.	d.	£	s.	d.
To MANAGEMENT :—						
Salaries	1,276	15	0			
Retiring Allowance	300	0	0			
Accountants' Fees	15	15	0			
Addressing of Circulars and Notices... ...	51	11	0			
Printing and Stationery	393	15	5			
Postage	649	13	3			
Telephone	17	0	0			
				2,704	9	8
" PUBLICATIONS :—						
Journal (Printing and Illustrating)	1,063	13	1			
"Science Abstracts" (Contribution)	920	0	0			
Wiring Rules	7	4	2			
Model General Conditions for Contracts ...	51	1	0			
				2,041	18	3
" MEETINGS :—						
Advance Proofs, Refreshments, &c.	143	12	0			
Reporting	58	16	0			
				202	8	0
" RENT, LIGHTING, AND FIRING				337	16	8
" INSURANCE				9	15	0
" DEPRECIATION :—						
Library (5 %)	68	8	11			
Furniture (5 %)	13	0	7			
				81	9	6
PREMIUMS				107	11	3
" CONVERSAZIONE (irrespective of Printing and Postage) ...				309	15	10
" ANNUAL DINNER				21	1	4
" LOCAL SECTIONS				321	13	1
" COMMITTEE ON ELECTRICAL LEGISLATION				48	10	6
" GENERAL EXPENSES :—						
Congratulatory Addresses to H.M. the King and to the Owens College, Manchester ...	18	13	10			
Coronation Decorations	10	0	0			
Memorial Wreath	5	5	0			
Sundries	92	1	0			
				125	19	10
" BALANCE carried to General Fund, being excess of Income over Expenditure				950	19	9
				£7,263	8	8

Electrical Engineers.

EXPENDITURE FOR THE YEAR DECEMBER, 1902.

Cr.

INCOME.

	£ s. d.	£ s. d.
BY SUBSCRIPTIONS FOR 1902 :—		
Received	6,173 17 6	
Outstanding (Estimated Value)	360 0 0	
		6,533 17 6
„ PUBLISHING FUND		1 1 0
„ DIVIDENDS ON INVESTMENTS :—		
Life Compositions	£165 17 4	
General Fund	157 8 1	
		323 5 5
„ INTEREST ON CASH ON DEPOSIT		30 15 3
„ JOURNAL :—		
Sales (Net Proceeds)	73 12 10	
Advertisements	300 16 8	
		374 9 6
		£7,263 8 8

LIFE

Dr.

	£	s.	d.
To Amount (as per last Account)	5,215	0	0
„ Life Compositions received during 1902	166	10	0
	£5,381	10	0

COMPOSITIONS.

Cr.

						£	s.	d.
By Investments (as per last Account) :—								
£400 0 0 New South Wales 4 % Bonds ...	£414	15	0					
318 0 0 Cape of Good Hope 4 % Consolidated Stock	306	0	0					
1,679 19 5 India 3½ % Stock	1,776	5	0					
120 0 0 South-Eastern Railway 5 % Debenture Stock	204	16	6					
355 5 10 Canada 3 % Stock	352	13	6					
289 17 4 Midland Railway 2½ % Consolidated Perpetual Preference Stock	274	11	10					
6 0 0 East Indian Railway Class "C" Annuity	185	1	9					
87 0 0 Great Eastern Railway 4 % Consolidated Preference Stock ...	130	15	2					
175 0 0 Great Eastern Railway 4 % Debenture Stock	251	5	5					
4 13 6 Great Indian Peninsula Railway "B" Annuity	120	1	6					
143 0 0 Southwark and Vauxhall Water Co. 4 % A. Debenture Stock...	207	17	9					
520 0 0 Staines Reservoirs 3 % Guaranteed Debenture Stock	539	2	3					
200 0 0 Glasgow and South-Western Railway 4 % Preference Stock (1894)	276	5	0					
29 0 0 Madras Railway 5 % Stock ...	44	9	4					
57 0 0 South Indian Railway 4½ % Debenture Stock	84	0	0					
30 0 0 Burma Railway Co.'s Stock ...	30	12	3					
						5,198	12	3
„ Investment Purchased in 1902 :—								
40 0 0 East Indian Railway 4½ % Debenture Stock						57	3	7
						£5,255	15	10
„ Balance uninvested carried to Balance Sheet						125	14	2
						£5,381	10	0

Dr.

		£	s.	d.
To Amount (as per last Account) :—				
Invested	£9,202 4 11			
Uninvested	195 13 10			
		9,397	18	9
„ Dividends received during 1902		277	2	9
„ Subscriptions received during 1902		207	14	0
„ Surplus from Vellum Diplomas		8	6	5
„ Amount transferred from General Fund in 1902		800	0	0
		£10,691	1	11

FUND.

Cr.

			£ s. d.
By Investments (as per last Account) :—			
£450 0 0	Canada 4 % Reduced Stock ...	£504 0 0	
524 13 0	Canada 3 % Stock	553 10 1	
181 0 0	Great Western Railway 4½ % Debenture Stock	324 17 8	
418 0 0	South-Eastern Railway 3½ % Preference Stock	555 18 9	
370 0 0	London and South-Western Railway Preferred Ordinary Stock ...	510 12 0	
520 0 0	London and South-Western Railway 4 % Consolidated Preference Stock	821 12 0	
190 16 8	India 3½ % Stock	229 9 6	
387 0 0	Great Eastern Railway 4 % Consolidated Preference Stock	575 17 8	
529 12 0	Midland Railway 2½ % Consolidated Perpetual Preference Stock ...	500 0 0	
23 7 5	Great Indian Peninsula Railway "B" Annuity	600 2 6	
80 0	London and South-Western Railway 3½ % Preference Stock	99 18 3	
504 0 0	Staines Reservoirs 3 % Guaranteed Debenture Stock	528 5 0	
670 0 0	Glasgow and South-Western Railway 4 % Preference Stock (1894) ...	925 11 9	
75 0 0	Great Eastern Railway 4 % Debenture Stock	107 13 7	
15 0 0	South-Eastern Railway 3 % Preference Stock	15 0 0	
220 0 0	Madras Railway 5 % Stock	340 0 5	
343 0 0	South Indian Railway 4½ % Debenture Stock	509 2 0	
320 0 0	South-Eastern Railway Preferred Ordinary Stock	511 1 0	
970 0 0	Burma Railway Co.'s Stock... ...	989 12 9	
			£9,202 4 11
„ Investment purchased in 1902 :—			
670 0 0	East Indian Railway 4½ % Debenture Stock		945 2 10
			£10,147 7 9
„ Balance uninvested carried to Balance Sheet			543 14 2
			£10,691 1 11

SALOMONS SCHOLARSHIP

Dr.

	£	s.	d.
To Amount (as per last Account)	2,126	19	3
	£2,126	19	3

SALOMONS SCHOLARSHIP

Dr.

	£	s.	d.
To Amount paid to Scholars in 1902...	62	10	0
„ Balance carried to Balance Sheet	80	1	2
	£142	11	2

DAVID HUGHES SCHOLAR-

Dr.

	£	s.	d.
To Amount (as per last Account)	2,000	0	0
	£2,000	0	0

DAVID HUGHES SCHOLAR-

Dr.

	£	s.	d.
To Amount paid to Scholars in 1902	50	0	0
„ Balance carried to Balance Sheet	45	13	6
	£95	13	6

WILDE BENEVOLENT

Dr.

	£	s.	d.
To Amount (as per last Account)	1,500	0	0
	£1,500	0	0

WILDE BENEVOLENT

Dr.

	£	s.	d.
To Amount invested in P.O. Savings Bank...	108	18	1
„ Balance uninvested carried to Balance Sheet	2	9	6
	£111	7	7

FUND CAPITAL.

				Cr.		
				£	s.	d.
By Investments :—						
£1,500 New South Wales 3½ % Stock ...	£1,556	5	9			
500 Cape of Good Hope 3½ % Stock ...	570	13	6			
				2,126	19	3
				£2,126	19	3

FUND INCOME.

	Cr.		
	£	s.	d.
By Balance (as per last Account)	72	16	6
„ Dividends received in 1902	69	14	8
	£142	11	2

SHIP FUND CAPITAL.

	Cr.		
	£	s.	d.
By Investment :—£2,045 Staines Reservoirs 3 % Guaranteed Debenture Stock	1,998	15	0
„ Balance uninvested carried to Balance Sheet	1	5	0
	£2,000	0	0

SHIP FUND INCOME.

	Cr.		
	£	s.	d.
By Balance (as per last Account)	34	10	3
„ Dividends received in 1902	61	3	3
	£95	13	6

FUND CAPITAL.

	Cr.		
	£	s.	d.
By Investment :—£875 Great Eastern Railway Metropolitan 5 % Guaranteed Stock	1,493	16	3
„ Amount invested in P.O. Savings Bank	6	3	9
	£1,500	0	0

FUND INCOME.

	Cr.		
	£	s.	d.
By Amount (as per last Account)	64	10	10
„ Dividends received in 1902	43	12	6
„ Interest	3	4	3
	£111	7	7

BALANCE SHEET,

Dr.

LIABILITIES.

						£	s.	d.
To Sundry Creditors						791	8	4
„ Local Sections :—								
Due to Hon. Sec. Dublin Section	£1	15	2					
do. do. Manchester Section ...	34	11	2					
do. do. Newcastle Section ...	6	11	9					
						42	18	1
„ Subscriptions received in advance :—								
On Account of 1903	154	18	0					
do. do. 1904, 1905, and 1906 ...	5	4	0					
						160	2	0
„ Salomons Scholarship Fund Income						80	1	2
„ David Hughes Scholarship Fund :—								
Capital uninvested	1	5	0					
Income	45	13	6					
						46	18	6
„ Wilde Benevolent Fund Income						2	9	6
„ Entrance Fees						849	6	0
„ Life Compositions uninvested						125	14	2
„ Building Fund uninvested						543	14	2
„ General Fund :—								
As per last Balance Sheet	5,751	12	7					
Add Excess of Income over Expenditure ...	950	19	9					
Subscriptions for years previous to 1902 received in 1902	374	10	0					
Subscriptions for years previous to 1902 outstanding on December 31st, 1902 (Estimated Value)	50	0	0					
	7,127	2	4					
Less Transferred to Building Fund	800	0	0					
						6,327	2	4
						£8,969	14	3

W. G. McMILLAN,
Secretary.

We beg to report that we have examined the above Balance Sheet and the Bankers' Certificates as to the Securities, and in our opinion the State- exhibit a true and correct view of the state of the affairs of the Institution at cost price. We hereby certify that all our requirements as Auditors have

ALLEN, BIGGS & CO.,
Chartered Accountants,
38, PARLIAMENT STREET, S.W.

24th April, 1903.

31st DECEMBER, 1902.

Cr.

ASSETS.

			£ s. d.
By Cash :—			
At Bankers		1,570 9 0	
Petty Cash		27 18 4	
			1,598 7 4
„ Local Sections :—			
In hands of Hon Sec. Birmingham Section...		6 0 7	
do. do. do. Glasgow Section ...		11 9 9	
			17 10 4
„ Investments, General Fund :—			
£1,418 8 0	Midland Railway $2\frac{1}{2}$% Consolidated Perpetual Preference Stock	£1,200 0 0	
918 3 2	India $3\frac{1}{2}$% Stock	973 17 10	
52 13 8	Great Indian Peninsula Railway "B" Annuity	1,239 17 9	
721 0 0	Madras Railway 5% Stock	1,114 14 0	
410 0 0	East Indian Railway $4\frac{1}{2}$% Debenture Stock...	586 1 7	
			5,114 11 2
„ Subscriptions in Arrear (Estimated Value)			410 0 0
„ Sundry Debtors			275 3 3
„ National Telephone Co. Deposit...			0 10 0
„ Furniture :—			
As per last Balance Sheet		251 11 2	
Additions during 1902		9 0 0	
		260 11 2	
Less Depreciation (5 %)		13 0 7	
			247 10 7
„ Books, Pictures, &c., other than the Ronalds Library :—			
As per last Balance Sheet		1,351 9 9	
Additions during 1902		17 8 9	
		1,368 18 6	
Less Depreciation (5 %)		68 8 11	
		1,300 9 7	
„ Stock of Vellum Diploma Forms		5 12 0	
			1,306 1 7
			£8,969 14 3

Statements of Account with the Books and Vouchers of the Institution, and ments are correct, and the Balance Sheet is properly drawn up so as to as shown by its books. The Securities have been included in the Accounts been complied with.

F. C. DANVERS
SIDNEY SHARP } *Honorary Auditors.*

The PRESIDENT: I have now to move that the Report of the Council as presented be received and adopted, and that it be printed in the Journal of the Proceedings of the Institution.

General WEBBER: I have great pleasure in seconding the proposal, more especially as the departure is a new one. Generally we have occupied the time of this meeting by reading this document, which is very interesting but, according to some of our friends, rather dry, at least, when it is read out. At the same time, knowing the immense amount of work that it represents on the part of our able Secretary, I think every one who reads it alone and at home will be interested and will recognise what he has done in the past year. I beg to second the proposal that has just been made to you by the President, that the Report be taken as read.

No further remarks being offered, the resolution was put to the meeting and carried unanimously.

The PRESIDENT: You have also had in your hands the Statement of Accounts, which were referred to in the Report, and which have been carefully examined and are certified as correct by the Honorary Auditors, Messrs. Danvers and Sharp. As you have had them before you, I do not want to occupy your time unnecessarily. I will formally move that the Statement of Accounts and Balance Sheet, of which copies were sent to the members with the notice convening the Annual General Meeting, be taken as read.

The motion was carried.

The PRESIDENT: I have now to propose, "That the Statement of Accounts and Balance Sheet for the year ending December 31, 1902, as presented be received and adopted."

Mr. ROBERT HAMMOND: I beg to second that, and would like to say that the accounts for the past year show a very healthy improvement upon those of the year before, due to the expansion of the Institution from year to year. The subscriptions show an increase for 1902 over 1901 of £880 10s. 6d.; the entrance fees show an increase for 1902 over 1901 of £232 13s.; our receipts from other sources of £224 13s. 4d.; and the expenditure shows an excess of only £374 3s. 5d.; the summary of the accounts therefore showing a net improvement of 1902 over 1901 of £963 13s. 5d.

The resolution was then put to the meeting and carried unanimously.

Mr. ROBERT HAMMOND: It gives me much pleasure to propose a vote of thanks to the Institution of Civil Engineers, who have in the past year, as they have kindly done in years gone by, placed their hall at our disposal. Of course the time may come when we shall have our own hall, but in the meantime we cannot express our gratitude too strongly to the Institution of Civil Engineers for their great kindness. The motion is, "That the best thanks of the Institution be tendered to the President, Council, and Members of the Institution of Civil Engineers for the great privilege of holding our evening meetings in the rooms of that Institution."

Mr. J. H. RIDER: I have much pleasure in seconding the vote of thanks to the Institution of Civil Engineers.

The resolution was put to the meeting and carried unanimously.

Mr. H. E. HARRISON: I have to propose, "That the members of the Institution of Electrical Engineers hereby express their cordial thanks to the Society of Arts for the great privilege of holding their evening meetings in May in the rooms of that Society." I need hardly say that it is a very great privilege to us when the Institution of Civil Engineers is unable to give us the use of its theatre that we should have friends like the Society of Arts on whom we may fall back to get us out of our difficulties. I have therefore very great pleasure in proposing this vote of thanks.

Mr. L. GASTER: I have much pleasure in seconding this vote. I have the pleasure of being a member of the Society of Arts myself, but I hope that it is not out of place for me to second the resolution.

The resolution was put to the meeting and carried with acclamation.

Mr. W. H. PATCHELL: The next resolution has been put into my hands—"That the thanks of the Institution be given to the Local Honorary Secretaries and Treasurers for their services during the past year." I think as time goes on we get more and more of the life of the Institution, not only in the Provinces but abroad, and the work done by the Honorary Local Secretaries and Treasurers is more and more in evidence, and we owe them an increasing debt of gratitude.

Mr. R. J. WALLIS-JONES: I have much pleasure in seconding the resolution that the thanks of the Institution be given to the Local Honorary Secretaries and Treasurers for their services during the past year.

The resolution was put to the meeting and carried unanimously.

Mr. E. O. WALKER: I have much pleasure in proposing "That the thanks of the Institution be accorded to Professor W. E. Ayrton and Mr. Robert Hammond, for their kind services rendered successively in the office of Honorary Treasurer during the past twelve months." I am sure that we all regret the occasion of Professor Ayrton, after so long a time fulfilling his duties with such great tact and kindness, having to resign his office on account of ill-health, and we owe him special thanks for all the work he has undertaken in connection with it. On behalf of the members I beg to thank Mr. Hammond for having so kindly consented to undertake the onerous duties of Treasurer, and to say that we shall value his services.

Mr. FLEETWOOD: I have great pleasure in seconding the motion.

The PRESIDENT: You have heard the motion put before you. I have no doubt it will be passed with acclamation as usual.

The resolution was carried by acclamation.

Mr. J. SWINBURNE: I have much pleasure in proposing a vote of thanks to the Honorary Auditors, Mr. Danvers and Mr. Sharp, and to the Honorary Solicitors, Messrs. Wilson, Bristows and Carpmael. We are all most grateful to business people who give up their valuable time to render services of that sort to the Institution.

Mr. W. DUDDELL: I have much pleasure in seconding the resolution.

The resolution was carried unanimously.

The PRESIDENT: I have now to announce that the candidates balloted for on the two lists are certified as duly elected.

Members.

Geo. Olver Donovan.
Joseph Richmond.
Charles Tothill.

Associate Members.

Robert M. Abraham.
William Adams.
Wm. Thomson Anderson.
Charles Jas. Beaver.
Arthur Bloemendal.
Joseph Norman Bulkeley.
Godfrey R. Chaplin.
Alan Ernest Leofric Chorlton.
Frederic Charles Geary.
Reuben Henry Harvey.
Percival Thomas Moor.
Henry Eoghan O'Brien.
Frank Augustus Parker.
Henry Mark Pease.
Geo. Gwendower L. Preece.
William Lincoln Smith.
John Robert Williams.

Associates.

Harry Bowthorpe.
Matthew Cable.
Chas. Wm. Clack.
Eustace Reginald Conder.
Wm. Griffith Counsell.
Dover Augustus G. de Horsey Farrant.
Arthur Frederic Fitzhardinge.
Horace William Woodness Henderson.
William A. Kennett.
William Hamilton Wilson.

Students.

Lennox Edelsten Agnew.
Frederick William Allen.
William Francis Bartram.
James Williamson Campbell.
Crellin Cartwright.
Chas. Bernard Catt.
Richard Chancellor.
Michael Dermot Cloran.
Harold Emmott.
Hugh Whitmore Franks.
Wm. Francis Furse.
Reginald Glanfield.
Albert Reginald Goonetilleke.
Evelyn Alfred Gurney-Smith.
Robert Harvey-George.
Herbert F. Hodges.
Walter Edward King.
Arthur Justin Patrick McCarthy.
Marcus Macdonald.
Patrick J. McElligott.
Richard Ward Passmore.
Francis E. Pingriff.
Sidney Reynill Smith.
Geo. Wilfred Stubbings.
Harold Dalbiac Taylor.
Clive Bennett Tutt.
Edward Bradford Ware.
Herbert R. Whiteley.

I have also to announce that no nominees having been received other than those announced at the Ordinary General Meeting on April 23rd, the Council nominees are, in accordance with No. 45 of the Articles of Association, duly elected to their respective offices, and the following constitute the Council and Honorary Officers for the twelve months 1903–1904 :—

President.

ROBERT KAYE GRAY.

The Past Presidents.

The Chairmen of Local Sections.

Vice-Presidents.

Dr. J. A. FLEMING, F.R.S.
JOHN GAVEY.
J. E. KINGSBURY.
Sir O. LODGE, F.R.S.

Members of Council.

Sir J. WOLFE BARRY, K.C.B., F.R.S.
T. O. CALLENDER.
S. DOBSON.
B. DRAKE.
S. Z. DE FERRANTI.
FRANK GILL.
F. E. GRIPPER.
H. E. HARRISON, B.Sc.
Lt.-Col. H. C. L. HOLDEN, R.A., F.R.S.
G. MARCONI.
W. M. MORDEY.
The Hon. C. A. PARSONS, F.R.S.
W. H. PATCHELL.
J. H. RIDER.
A. A. CAMPBELL SWINTON.

Associate Members of Council.

W. DUDDELL.
SYDNEY MORSE.
A. J. WALTER.

Honorary Auditors.

FREDERICK C. DANVERS.
SIDNEY SHARP.

Honorary Treasurer.

R. HAMMOND.

Honorary Solicitors.

Messrs. WILSON, BRISTOWS, & CARPMAEL.

Mr. HAMMOND: I have pleasure in moving a very hearty vote of thanks to our President for presiding at this meeting to-day.

Mr. W. MCGREGOR: I do not think that it requires any seconding, but coming as I have from a long distance, I should like to join in expressing what pleasure we have in attending this meeting, and I second the vote of thanks to our President.

The PRESIDENT: I am very much indebted to you, gentlemen, for your kindness.

OBITUARY NOTICES.

SIR FREDERICK AUGUSTUS ABEL, who passed away at his residence in Whitehall Court on the 6th of September, 1902, was born on the 17th of July, 1827, in Poland Street, Oxford Street.

At the age of seventeen he commenced his studies under Dr. Ryan at the Royal Polytechnic Institution, and a year later entered the then newly-formed Royal College of Chemistry, where he worked under Hofmann, first as pupil and then as assistant. In 1847–8–9 he read his first three papers before the Chemical Society. In 1851 he became lecturer in Chemistry under Stenhouse at St. Bartholomew's Hospital, and in 1853 succeeded to the Chair of Chemistry, previously occupied by Faraday, in the Royal Military Academy at Woolwich. Whilst here, he was appointed to be, first the scientific adviser, and then, in about the year 1854, chemist to the War Office.

From 1854 to 1888 he held the last-named position, and was thus intimately associated with the modern development of explosives and the applications of steel to naval and military purposes. His name will always be specially remembered in connection with gun-cotton and cordite, with the masterly researches on explosives in which he collaborated with Sir Andrew Noble, and with his recommendations on the mode of testing the flash-point of petroleum. In course of his work at the War Office, Sir Frederick necessarily gave much attention to the application of electricity to submarine mining and for military purposes generally. In 1874 he read before the Institution, then the Society of Telegraph Engineers, a paper embodying some of his experiences, and entitled "Notes relating to Electric Fuses." In 1887 Sir Frederick became the Organising Secretary of the Imperial Institute.

A brilliant and indefatigable worker in many fields of labour, the estimation in which he was held by his fellows is shown by the long list of distinguished positions that he held. Sir Frederick Abel was President of the Chemical Society from 1875 to 1877, of the Institute of Chemistry in 1881 and 1882, of the Society of Chemical Industry in 1883, of the Chemical Section of the British Association in 1887, of the Iron and Steel Institute in 1891, and of the British Association at Leeds in 1890. He had also acted as Chairman of the Council of the Society of Arts, and as Chairman of the Executive Committee of the City and Guilds of London Institute. He received the Companionship of the Order of the Bath in 1877, and, after having been knighted in 1883, became K.C.B. in 1891; he was made baronet in 1893, and in 1901 received the Grand Cross of the Royal Victorian Order. In addition to the above honours, he received honorary degrees at Oxford and Cambridge, and was at different times the recipient of the Albert, Royal, Telford, and Bessemer Medals.

Sir Frederick Abel was elected a Member of this Institution, then the Society of Telegraph Engineers, on the 16th of November, 1871; he was a Member of Council in 1873 and 1874, Vice-President in 1875 and 1876, and President in 1877. From 1887 to the time of his death

he was one of the Trustees of the Institution, and although, during his later years, the pressure of other engagements, together with impaired health, prevented his attending the Meetings of the Institution, he continued to the end to take a keen interest in its work.

J. S.

FREDERICK BATHURST, born in 1866, was the eldest son of Colonel Bathurst of the Coldstream Guards, and grandson of General Sir James Bathurst.

His electrical career commenced at Finsbury Technical College, where he went through a course under Professor Ayrton, after which he was articled to the late firm of Woodhouse & Rawson, Limited. In 1889 he went to the United States, and after visiting many places of interest, obtained an important position at the works of the Edison General Electric Co., where he was associated with Mr. Edison in his laboratory experiments. He remained with Mr. Edison until 1894, when he was summoned home to the death-bed of his father; after this Mr. Bathurst took a long holiday in France, Germany, Holland and Switzerland, with the object of acquiring information regarding electrical progress in those countries. He then returned to the United States, where he took leave of the many friends he had made during his previous stay there, and, on returning to England, took over the Conduit Department of the General Electric Co., Ltd., and introduced the Insulated Conduit System in this country. He devoted great personal energy to the work, and was rewarded with a large measure of success.

He remained with the General Electric Co. for about four years, when the owners of the patents decided to form a separate company in order to advance the interests of Insulated Steel Conduit still more, and Mr. Bathurst joined the Conduit & Insulation Co. for this purpose. After two or three years, however, he found that his energies were somewhat fettered in a Limited Company, and he decided to become a free agent in order to develop the system alone. He, therefore, severed his connection with this Company, and, at the moment of his untimely death, was arranging to put on the market further improvements and new lines of Steel Conduit.

In 1897 he married Florence, second daughter of Mr. Thomas Sellars of Nottingham, by whom he had two sons, one of whom unfortunately pre-deceased him. At the time of his marriage the remembrance which gave him the greatest pleasure was a signed photograph from Mr. Edison, "Wishing Bathurst all good luck and happiness on his wedding day."

Mr. Bathurst was an indefatigable worker, and all that he did was carried out with that push and energy which was characteristic of the man, and which unfortunately appears to have overstrained his constitution. Besides his actual ability for business he was also an able speaker and writer, as was instanced by the papers which he read before various societies, of which may be specially mentioned that entitled "The Electric Wiring Question," read before the Institution on the 28th of November, 1895, and published in the Institution Journal vol. 24,

p. 582. One of the papers which earned for him special distinction was that on "Prevention of Fire Risk," for which he was awarded by the Society of Arts a premium of £25 and their Gold Medal.

For many years he had been subject to asthma, and on the 27th of September, 1902, after a severe attack, he retired to rest and passed away in his sleep.

He was a man for whom all who came in contact had great respect, not only by reason of his business qualifications and the enthusiasm that he had for his particular hobby, but also for his sterling personal qualities, and his death occasioned the greatest regret amongst all members of the electrical profession.

Mr. Bathurst was elected a Student of the Institution on the 14th of February, 1884, and was transferred to the class of Associates on the 14th of February, 1889, and to the class of Associate Members on the 9th of February, 1899. V. Z.

FRANK BOLTON, who had occupied the post of Superintendent of the Eastern Telegraph Company at Trieste, Austria, since 1882, and had acted as that Company's agent with the Austrian Government since 1891, was the third son of the late Dr. John Bolton, of Mauritius, and was born in 1853.

After being educated privately, he entered the service of the predecessors of the Eastern Telegraph Company in 1869, going to Malta, where he remained till 1878, when he was appointed the Company's Superintendent at Salonica, whence he went to Trieste.

Mr. Bolton represented the Eastern Telegraph Company at the International Telegraphic Conference at Buda-Pesth some years back, and, but for his death, would have been present in a similar capacity at the Conference now being held in this country.

Mr. Bolton, who was a man of considerable ability and an accomplished linguist, was much esteemed by those with whom he came in contact.

He died at Trieste on the 8th of January, 1903, leaving behind him a widow (having married a Swiss lady, Miss Zoller, of Frauenfeld, Canton Thurgau) and three children.

Mr. Bolton was elected an Associate on the 12th of December, 1877, and was transferred to the class of Members on the 8th of November, 1883. G. A. B.

EDWARD TREMLETT CARTER, the Editor-in-Chief of the *Electrician*, was born in Calcutta in 1866, and was the eldest of ten surviving children. He was brought to England at an early age, and was educated privately at Bristol, afterwards at the Merchant Venturers' College in that city, and finally at the Bristol University College, where he went through the Engineering and Physics courses under Professor Hele Shaw and Professor Silvanus P. Thompson. Mr. Carter was for a short time demonstrator at the Bristol University College until he obtained an appointment at the School of Electrical Engineering and Submarine Telegraphy, Hanover Square, as assistant to the late Mr. Lant Carpenter, who was then principal. He was afterwards one of the

lecturers at this school, where he organised several courses of lectures and practical training in mechanical engineering, machine design, and other branches of engineering, one of which formed the basis of a series of articles orginally published in the *Electrician* on "Motive Power and Gearing for Electrical Machinery"; these articles were subsequently collected, revised, and issued in book form.

During this period of his career Mr. Carter was a frequent contributor to the technical press, and also carried on a small practice as consulting engineer.

On the closing of the School of Electrical Engineering in 1893, Mr. Carter joined the permanent staff of the *Electrician*, of which Mr. A. P. Trotter was then editor, and, on Mr. Trotter's retirement in 1895, he was appointed assistant-editor under Mr. W. G. Bond as editor. In 1897 Mr. Carter went over to Montreal to attend the meeting of the British Association for the *Electrician*, and afterwards made a prolonged tour in Canada and the United States. Shortly after his return he succeeded Mr. Bond as editor-in-chief.

Mr. Carter invented several things in connection with engineering, for some of which he took out patents; he also, in the intervals of his professional duties, indulged himself in the writing of fiction, several of his shorter stories being published in magazines, and one, at least, in book form; he was also very fond of music.

Mr. Carter had never a strong constitution, and in the winter of 1899, after a severe attack of pleurisy and bronchitis, following after influenza, had to leave his work and make a two months' tour to the Mediterranean and Egypt; this set him up again temporarily, but unfortunately the improvement in his health was not permanent. Last October it was found that his lungs were badly affected, and he went to a sanatorium to follow the "open-air cure." Unfortunately the insidious disease had taken too great a hold on his never strong constitution, and he succumbed to it on April 16th, aged 37 years, at Clevedon in Somerset, where he was devotedly nursed by his wife, having left the sanatorium when it was seen that the treatment was not benefiting him. Mr. Carter's loss will be deeply felt by his friends, for he had a most lovable nature, as well as by his widow and three sons.

Mr. Carter was elected an Associate of the Institution on the 23rd of February, 1888, and was transferred to the class of Members on the 23rd of May, 1895; he was also a member of the Société des Ingénieurs Civils de France, a Fellow of the Royal Astronomical Society, and of the Physical Society of London. F. C. R.

FRANCIS T. BRISTOW DANIELL, the son of Captain Daniell, an Indian artillery officer who was killed in the Mutiny, was born on the 25th of July, 1838, was educated at a private school in England, and went out to India as a Morse instructor under Sir W. O'Shaughnessy. He was transferred to the Mehran Coast as inspector about the year 1862, and afterwards to Persia in 1863, where he assisted in the erection of the Persian lines. On the completion of this work he was appointed traffic manager. On the reorganisation of the Indo-European

Telegraph Department in 1887 he became superintendent, a position which he retained until, in August, 1891, he retired on a pension. He died at Brussels on the 17th of April, 1903.

Mr. Daniell was elected an Associate on the 27th of November, 1872, and was transferred to the class of Members on the 24th of February, 1875.

BERTRAM ANNANDALE GIUSEPPI was born on January 27th, 1872, and educated at Kensington Grammar School and King's College. He joined the Electrical Standardising Testing and Training Institution, at Faraday House, in 1890, to gain a technical training in electrical engineering, for which he had in early life exhibited a marked ability.

In 1891 he entered the works of Messrs. S. Z. de Ferranti, Limited, leaving again in 1892 to join the staff of the British Insulated Wire Company, Limited, with whom he was connected until 1901. Mr. Giuseppi then joined the staff of the South Lancashire Electric Traction and Power Company, Limited, as second engineer, and held this post at the time of his decease. His health had been bad for a number of years, and on June 23rd, 1902, he left his rooms in the morning to proceed to business, but not feeling well on the way, returned home, and died immediately.

Mr. Giuseppi joined the staff of the British Insulated Wire Company in its earliest days, and took a prominent part in the organisation of the factory, in the experiments for the determination of the properties of paper-insulated cables, and in the laying down and early working of the Prescot and District Electric Supply Works, one of the earliest provincial stations to be established for the sale of electric energy.

He subsequently carried out many important works for the British Insulated Wire Company, among them being the laying of high-pressure cables in Malta and Buenos Ayres, being engaged in the latter place for nearly two years.

Mr. Giuseppi played a prominent and most successful part in the difficult negotiations with the many local authorities through whose districts the lines of the South Lancashire Tramways run. It was, however, as an engineer that his abilities were particularly marked, and although he was still a young man at the time of his death, the Industry has undoubtedly lost a member of considerable experience and exceptional technical knowledge.

He was elected a Student on the 19th of February, 1891, transferred to the class of Associates on the 27th of January, 1893, and again to the class of Associate Members on the 8th of March, 1900. G. H. N.

JOHN HALL GLADSTONE was born on the 7th of March, 1827, and was educated at home. He studied chemistry at University College, London, under Graham, and at Giessen under Liebig, taking his Ph.D. degree in 1848. On returning to England, he lectured on chemistry at St. Thomas's Hospital from 1850 to 1852. His subsequent scientific research work was done in his own private laboratory, with the exception of the three years 1874 to 1877, when he held the Fullerian Professorship of Chemistry at the Royal Institution. Quite early he

was attracted by problems arising out of the composition and action of explosives, and investigated fulminic acid, iodide of nitrogen, gun-cotton, and xyloidine. In consequence of this work he was made a member of the Gun-cotton Committee appointed by the War Office, 1864–1868.

Even earlier—1859–1862—he had become a member of a Royal Commission on lighthouses, buoys, and beacons, writing the greater part of the Report and a good deal of the Appendix.

His original work in physics and physical chemistry was very fruitful. In 1897 he had written seventy-six papers himself, and forty-seven in conjunction with other workers. A paper on Chemical Affinity occupies forty-five pages of the *Philosophical Transactions of the Royal Society* for 1855. A long series of papers (with Mr. Tribe) on the copper-zinc couple and its applications conferred a distinct boon on organic chemistry. The chemistry of secondary batteries was first made known by Dr. Gladstone and Mr. Tribe, physical causes for their varying E.M.F. being subsequently investigated in conjunction with Mr. Hibbert.

In optics and chemical optics Dr. Gladstone's investigations led to a "law" which is constantly being used at the present time. It deals with the relations between the refractive index of a body and its density, and the general results will have to be considered in reference to corresponding changes in the dielectric constant. By prolonged researches he obtained consistent values for the refractive equivalents of the elements, and provided data of much value in certain optical problems.

A glance at the index to Ostwald's *Lehrbuch* will show how much Dr. Gladstone had to do with laying the foundations of physical chemistry. He was awarded the Davy Medal by the Royal Society, 1897.

Dr. Gladstone held many offices. He was the first President of the Physical Society, 1874–1876, and President of the Chemical Society, 1877–1879. He was elected a Fellow of the Royal Society in 1853, and served on the Council for many years. A member of the British Association from 1849 onwards, he served on the committee of Section B. for fifty years, and was president of the Section in 1872 and in 1883.

Dr. Gladstone had other and strong interests beside science. He served for twenty-one years on the London School Board. Here also he was a pioneer. When he began to advocate science teaching as a part of the ordinary day-school work, there were not so many sympathetic listeners as at the present day. In committee work he was most assiduous, and only those who were familiar with him could appreciate his daily contribution to the cause of reformed popular education. Besides this, there was much philanthropic work hidden from the public. An abiding support of broad and helpful religion was a most striking feature in his character.

Dr. Gladstone was twice married, first in 1852 to May, daughter of the late Charles Tilt, and secondly to Margaret, daughter of the late Rev. D. King, niece of Lord Kelvin.

He was elected a Member of the Society of Telegraph Engineers, now the Institution of Electrical Engineers, on the 11th of December,

1872. In 1887 he was elected a Member of Council, and in 1892, in conjunction with Mr. W. Hibbert, contributed a paper "On the Cause of the Changes of Electromotive Force in Secondary Batteries," read before the Institution on the 12th of May, 1892, and printed in the Journal, 1892, Vol. 21, p. 412. W. H.

HENRY THOMAS GOODENOUGH, late Electrical Engineer-in-Chief to the Great Western Railway Company, the service of which he entered on the 20th of May, 1863, as a lad clerk at the age of sixteen.

By assiduity and careful attention to his duties he was, in November, 1864, appointed travelling or instructing clerk. On the 14th of February, 1866, he was transferred to the Superintendent's office at Paddington; and on the 11th of August, 1888, when this Company by amalgamations with the South Wales, South Devon, Cornwall, and other smaller lines of railway reached a mileage of 2,600 miles, he was appointed Divisional Electrical Engineer for the northern division of this railway.

On the 1st of August, 1892, on the retirement of Mr. Spagnoletti, he was appointed to succeed him as Chief Electrical Engineer to the Company.

He was not constitutionally a strong man, and he was taken ill in the beginning of April, 1903, and after a short illness he died on the 15th of April, of "general peritonitis," at his residence at Slough.

He is very deeply regretted by his family, friends, and colleagues, and by his death the Great Western Railway Company has lost a zealous, conscientious, and anxious officer.

He was elected a Member on the 11th of February, 1886.

C. E. S.

ADOLPHUS GRAVES, Telegraph Superintendent of the North Eastern Railway, died at his residence at York, on the 19th of January, 1903, at the comparatively early age of 64 years. Entering the service of the Electric and International Telegraph Company in 1852, Mr. Graves had almost completed his Jubilee in the telegraph service when an attack of paralysis necessitated his retirement in October, 1902.

On the acquirement of the telegraphs by the State in 1870, the railway companies, who were even at that date probably the most extensive users of the telegraph, were left free to provide and maintain their own lines, and Mr. Graves was appointed to the post of Telegraph Superintendent by the Directors of the North Eastern Railway, with his headquarters at York. The appointment involved the creation of a new department of the railway service, and Mr. Graves' organising abilities rendered him particularly fitted for the task.

Dating from the time of Mr. Graves' appointment, railway telegraphy was destined to great development. Attention was being largely directed to the question of the safe operation of railways, and almost the first thing Mr. Graves was called upon to do in his new position was to install the block-system throughout the North Eastern system. Naturally, so large an extension of the service involved heavy work for the chief executive officer, complete reorganisation and a considerable

increase of staff. Further work of a similar character was necessitated later by the absorption by the North Eastern of other lines such as the Stockton and Darlington, the Blyth and Tyne, and others which, combined, now make up one of the most important railways in the kingdom. The system of block-working established by Mr. Graves--the 3-wire, single needle system—is still in use throughout the line, and it is indicative of the soundness of his judgment that the system and apparatus decided upon then is now more extensively used than any other for block signalling.

The introduction of the telephone at a little later period led to a further development of Mr. Graves' department. The very large use made of the telephone for traffic arrangements necessitated the erection of numerous lines in all parts of the system, and most careful supervision of circuit arrangements in order to produce the best results from a service point of view. It is probable that the introduction of the telephone involved even more consideration on the part of a conscientious executive officer than the establishment of the block system, since, whilst the latter followed regular and well-defined routes, the former had to be taken to all kinds of out-of-the-way places, and required the greatest possible care in order to prevent overlapping without restricting use.

Still later, in 1891, the North Eastern Railway introduced the electric light in their Hotel and offices at York, and Mr. Graves took charge of the plant, and of all further extensions, and he retained this branch of electric work until within about 15 months of his retirement. During this time plants for which he was responsible were laid down at Tyne Dock, Blyth, and Middlesbrough, and the original station at York was remodelled and finally removed to a new site. Electric light was installed at many other points on the North Eastern Railway during Mr. Graves' supervision, supply being taken from local public mains. At the time Mr. Graves relinquished this work, the consumption of electrical energy by the North Eastern Railway Company was considerably over a million units per annum.

At an early period Mr. Graves became impressed with the advantages that copper-wire possessed over iron-wire for overhead construction under certain circumstances. In the neighbourhood of large towns where space is scarce and railway telegraph lines converge, the large number of wires made it difficult to construct satisfactory lines, from a mechanical standpoint, if iron wires of the usual gauge were used. Moreover, the deterioration of iron-wire was very rapid in the neighbourhood of large works, such as were established at many points on the North Eastern system. For these reasons Mr. Graves was led to experiment with copper as a substitute for iron in such places, and he was more than satisfied with the results obtained, and consistently advocated its use under similar conditions. Some misapprehension arose a few years ago with reference to the extent of Mr. Graves' claims, but he himself never claimed more than is here indicated.

Mr. Graves was of a modest and retiring disposition, and possessed of a most equal temperament. His chief characteristics were his capacity for work, his untiring industry, and his entire devotion to the

interests of the great Company that he served for nearly 32 years. To the last he kept the whole of the work of his department in his own hands, and directed operations as at the beginning of his career. No detail was too trivial for his personal attention, and he never seemed to realise that the amount of work he put upon himself was greater than was desirable.

In his personal relations Mr. Graves was ever the most courteous of men, considerate and patient with wrong-doers of the minor order, and helpful to all his fellows. Up to the last two or three years of his life he was very active, and his figure was known to all classes of railway-men from Berwick to Doncaster, and from Carlisle and the West Riding to the North Sea. Probably no other prominent official was so well known to men in remote parts of the line.

Mr. Graves was an original member of the Society of Telegraph Engineers, and, although he was of too retiring a disposition to take part in the discussions, or to appear publicly before it in any capacity, he always took a keen interest in its proceedings. J. P.

LEOPOLD WILLIAM HEATH was born in London, December 23rd, 1872. Educated at the Central Foundation School, Cowper Street, he entered, in October, 1889, as a day student at the City and Guilds' Technical College, Finsbury, in the Department of Electrical Engineering, and after two years of earnest study he was awarded the College Certificate. He was at once offered a Senior Studentship in the Department of Mechanical Engineering, under Professor John Perry, whom he assisted in several investigations, including one on the application of Spherical Harmonics to the distribution of magnetic field around a solenoid. In July, 1892, on the completion of this additional year of studies, he entered the service of the Galway Electric Lighting Company. and in April, 1894, joined the engineering staff of the Blackpool Corporation Electric Tramways. A year later he entered the service of Messrs. Veritys at their Manchester branch, and in 1898 was appointed by the same firm to be manager of one of the departments of their factory at Birmingham. In 1900 he returned to the service of the Galway Electric Co. as their manager, but after a few months he exchanged this post for an appointment as designing engineer under the British Thomson-Houston Co., an appointment which brought him back to London. He was in 1901 also appointed to be lecturer in Applied Mathematics at the Northampton Institute in Clerkenwell. Early in the summer of 1902 he left England to study certain new developments in the works of the General Electric Co. at Schenectady, N.Y., and there on July 3rd, 1902, he met his death by electric shock through a defective switch in the laboratory. His untimely death cut short a very promising career. He had the capacity for great things; the patience of mind to watch for their development; and a sincerity and tenacity of purpose which gave assurance of success.

He was elected a Student on Feb. 11th, 1892; transferred to the class of Associates on May 8th, 1894, and to the class of Associate Members on Feb. 9th, 1899. S. P. T.

GEORGE ROBERT MOCKRIDGE was born at Bristol in 1854, and entered upon his telegraphic career in 1869. Five years later he joined the service of the Direct United States Cable Company, and served them successively in Torbay, Nova Scotia, Rye Beach, New Hampshire, and Boston, Massachusetts. In June, 1881, he resigned his appointment with that Company to take up the superintendency of the Penzance station of the Western Union Company. Here he remained until the time of his death, which occurred at Penzance in March, 1903, after an illness of a few weeks' duration. Of a robust constitution, his early death came as a great shock to the many friends that he had made in the course of an active life. His character was summed up as follows in an appreciative article from the pen of a colleague, written in the *Penzance Evening Tidings* of March 30, 1903: "Of a happy and optimistic disposition, true-hearted, open-handed and ever ready to help, conscientious in his dealings with his fellow-men, and in the best essentials a gentleman."

Mr. Mockridge was elected a Member of the Institution on the 23rd of January, 1896.

JAMES HENRY SECCOMBE, who died in 1902, at the early age of 35, received his early training in New York. From 1893 to 1896 he was with the Western Electric Company; then, for a twelvemonth, he served with the General Electric Company in New York, leaving them in 1897 to join the Sprague Electric Elevator Company. In 1898 he came to England on behalf of the last-named Company to assist in putting down electric-lift plant for the Central London Railway. When the railway was opened, Mr. Seccombe was taken over by the Railway Company as Electrician in charge of the lift equipment. His health, which had for some time been failing, gave way shortly afterwards, and he was compelled to take a long sea-voyage. Unfortunately, the rest and change had not the desired effect, and he died shortly after his return.

Mr. Seccombe was elected an Associate Member of the Institution on the 9th of January, 1902.

SIDNEY H. SHORT was born in Columbus, Ohio, U.S.A., in 1858, and received his early education in that city, afterwards passing in to the Ohio State University, where he graduated as a Bachelor of Science. During two years he was a teacher of Physics and Electrical Engineering in the University in which he graduated, and was afterwards, for five years, Professor of Physics and Chemistry in the University of Colorado.

In 1885 he began to work at the construction of electric apparatus and the equipment of electric railways. In 1889, in association with Mr. Brush, he formed and became President and Chief Engineer of, the Short Electric Railway Company of Ohio. He was also Chief Engineer of the Brush Electric Company of Cleveland, Ohio. In 1892 the Short Electric Company was merged in the General Electric Company of America, and Professor Short became a member of the Technical Board of this Company. In 1893, however, he left to take up the position of Vice-president and Chief Engineer of the Walker Company

of Cleveland, which manufacturing generators and motors of his design, rapidly developed, and was in 1898 absorbed by the Westinghouse Company. Professor Short then came to England, where he joined the English Manufacturing Company as Technical Director, and arranged for the erection of the Preston Works, which were soon in a position to commence work. All too soon afterwards he succumbed to an attack of appendicitis.

Professor Short was a prolific inventor, and was well known by his writings. His loss will be keenly felt not only by those who had the privilege of his friendship, but by many to whom he was known only by fame. He was elected a Member of the Institution on the 10th of January, 1901, and was a valued member of the Committee on Traction, Light and Power Distribution.

CARL FREDERIK TIETGEN, who died on the 19th of October, 1901, was born at Odense on the 19th of March, 1829. He was educated for the most part in England, and worked for some years in Manchester. Having returned to Copenhagen in 1855, he became a few years later the managing director of the *Privat Bank*, which was founded about that time.

He devoted much thought to submarine telegraphy and was actively associated in the work of the North Atlantic Telegraph Company, which was founded in March, 1866, to carry out his scheme for the establishment of telegraphic communication between the Northern part of Europe and America, *viâ* Iceland and Greenland, but the British Atlantic Cable was laid shortly afterwards, and the Danish Atlantic Cable was not proceeded with. Mr. Tietgen's attention was then devoted to the laying of cables between the Northern countries of Europe and this country, and in this work he was associated with Mr. H. G. Erichsen of Copenhagen, and Mr. J. Newall of Gateshead. Commencing in 1867, three companies were formed, the Danish-Norwegian-English Telegraph Company, the Danish-Russian Company, and the Norwegian-British Company. The first of these, with Mr. Tietgen as Chairman, laid a cable between Denmark and England, the second a cable between Denmark and Russia. The three companies, in 1869, amalgamated under the name of the Great Northern Telegraph Company of Copenhagen and, at that time, owned over 1,000 miles of cable. In 1870, Mr. Tietgen formed the Great Northern Telegraph China and Japan Extension Company, which was also merged in the Great Northern Telegraph Company.

He was Chairman of the latter company from the first up to 1897, when, owing to failing health, he found it necessary to retire from active duties. Even then, however, he did not severe his connection with the company, but accepted the position of Honorary Chairman.

Mr. Tietgen occupied a most distinguished position in Denmark, having been closely identified with the development of the country and of its enterprises; and in due time became a Privy Councillor. He also received the Grand Cross of the Order of the Dannebrog.

He was elected a Member of the Institution on the 29th of March, 1872.

CHARLES GRANVILLE VINES, born in 1873, was educated at Christchurch School, Oxford, and at Rossall. He served his apprenticeship, from 1890 to 1894, with Messrs. Robey and Co., of Lincoln, attending at the same time evening classes at the Lincoln School of Science and Art. He was subsequently employed by Messrs. Willans and Robinson, working in their outside department at the City of London Electric Light Company's works at Bankside.

In 1897 he went to South Africa, where he was engaged in engineering work at Belingwe and at Johannesburg.

In 1899 he went to Kimberley as manager of Mr. Reunert's electrical works. During the siege of Kimberley he served as a non-commissioned officer in the Veterans' Company of the Town Guard, having previously served as a volunteer while at school. On the completion of the electric light installation he was unanimously elected Borough Electrical Engineer by the Kimberley Town Council. And then, when his future seemed assured, he contracted typhoid fever and, after an illness of three weeks, died at Kimberley on the 28th of March, 1902, at the early age of twenty-nine.

He was elected an Associate Member of this Institution on the 10th of January, 1901, and was also an Associate Member of the Institution of Mechanical Engineers.

JAMES WIMSHURST, born on the 13th of April, 1832, was the son of Mr. Henry Wimshurst, who was the first successfully to apply the bladed screw propeller to steamships, and who designed, built, and owned the two first screw-propelled vessels, the *Archimedes* and the *Novelty*.

Mr. James Wimshurst was apprenticed to shipbuilding and engineering at the works of the late Mr. Joseph Mare, now the Thames Iron Works, Limited. Upon completion of apprenticeship he was appointed to the staff of Lloyds Registry of Shipping. After some years he left Lloyds to take up an appointment as Chief of the Staff of the Liverpool Underwriters Registry, and resigned this position, after ten years, to join the Board of Trade as Chief Shipwright Surveyor in the Consultative Department at Whitehall, a post from which he retired three years ago, shortly after reaching the age limit.

During the whole of his career Mr. Wimshurst had devoted the greater part of his leisure time to scientific and mechanical research, and in all houses in which he lived had fitted up large workshops, equipped with benches, lathes, and other tools driven by power, and it was there that he made with his own hands the various devices and apparatus which he invented and with which his name will always be associated. Whilst taking the keenest interest and closely following up the latest scientific and mechanical inventions of all kinds, the subject in which he mostly interested himself was very high-tension electricity, and for the last twenty years of his life he always had some dozen or twenty induction or influence machines of all sorts and kinds in his workshops to experiment upon.

In 1881 a description was published in *Engineering* of a new type of influence electrical machine, and, being interested, he immediately

made one from the written description, but not being contented wi h the results, he built an improved form of machine of the Carré type. Later he designed and built several machines of the Holtz type, but having the fixed plates supporting the armature cut of rectangular shape and differently coupled; both of these alterations were found greatly to increase the output, and to rectify the difficulty of getting mixed poles. Some of these machines were very large and powerful, and in their day exceeded all others in both efficiency and size. They were fully described in *Engineering* at the time, and are generally known as Wimshurst's Improved Holtz Machine.

Shortly after this, Mr. Wimshurst designed the well-known influence machine bearing his name, having two plates rotating in opposite directions, this type of machine being remarkable for the great output, the ease with which it excites itself, and its simplicity of construction. It would be difficult to overestimate the value of such a machine in the laboratory or the lecture theatre on account of its great reliability in exciting itself, and it is a matter of interest to note that Mr. Wimshurst hit upon the exact and right proportions in the design of his first machine, such as are found even to this day to be most efficient. His inventive nature led him to design many other forms of this same machine, having cylindrical plates, radial arms, or double coating with paraffin, double plates laid against each other on the same driving boss. All these were tried, but to no practical advantage, and were dropped.

It may be mentioned that the greatest regret and disappointment experienced lay in the fact that he did not patent the invention, and therefore had no control over the design and manufacture of the machines as he would have liked to have, not from a financial point of view, but merely to see that none but well-fitted and well-designed machines were made for sale, for his thoroughly sound engineering mind could not view with indifference much of the trashy and defective apparatus that he saw sold to the public. The best proportions having been ascertained, larger and larger machines were constructed. Then, after the discovery of the Röntgen-tube and X-rays, when applying a tube to the terminal of the machine, it was found to be fully illuminated, and a further field for research was thus opened out. The influence machine is found to be of great value for screen work, giving a steady light with considerable penetration, and with entire immunity from the very dangerous X-ray burns which are possible in using the heavy current from battery and coil.

Another highly important application of the Wimshurst machine is the production of exceedingly high-tension brush discharges, which are found to be very efficacious in the cure or reduction of lupus, rodent ulcer, cancer, and consumption. Most large hospitals are equipped with the Wimshurst machine, and in the United States, especially, the machine is used extensively.

Mr. Wimshurst throughout his career devoted his day hours to the business of shipbuilding and engineering, but the whole of his leisure he gave up to experimental research; nothing gave him greater pleasure than to work with and to entertain and help his scientific

friends in his workshops. He was a most original thinker, and was always at work designing apparatus, taking the greatest pleasure in endeavouring to test the truth of the various theories of the day. He was a Fellow of the Royal Society, a Member of Council of the Physical Society, Member of Council of the Röntgen Society, Member and one of the Managers of the Royal Institution, Member of the Institution of Naval Architects, Hon. Member of the Institution of Marine Engineers. He was exceedingly simple in his tastes and mode of living, most generous and hospitable, a good friend to a great number of young men whom it was his greatest pleasure to assist. His loss will be regretted by these and by his large circle of friends.

Mr. Wimshurst was elected a Member of the Institution of Electrical Engineers on the 10th of June, 1889. J. E. W.

REFERENCES TO PAPERS READ BEFORE LOCAL SECTIONS OF THE INSTITUTION, AND PUBLISHED, IN FULL OR IN ABSTRACT, IN THE TECHNICAL PRESS, BUT NOT YET ORDERED TO BE PRINTED IN THE JOURNAL OF THE INSTITUTION.

BIRMINGHAM LOCAL SECTION.

"Gas Engines for Electric Lighting," by H. B. Graham, Associate.
Electrical Review, Vol. **52,** p. 242, February 6, 1903.
Eletrical Times, Vol. **23,** p. 178, January 29, 1903.
Electrician, Vol. **50,** p. 594, January 30, 1903.

"Power Transmission by Gas," by Prof. F. W. Burstall.
Electrical Times, Vol. **23,** p. 564, April 2, 1903.

DUBLIN LOCAL SECTION.

"Vacuum Tubes as Lightning Arresters," by A. T. Kinsey, Associate.
Electrician, Vol. **50,** p. 390, December 26, 1902.

"Economising Wire in House Wiring," by W. Tatlow, Associate Member.
Electrician, Vol. **50,** p. 417, January 2, 1903.

"Railway Carriage Lighting by Electricity," by J. H. Dowling, Student.
Electrical Engineer, Vol. **31,** p. 128, January 23, 1903.
Electrician, Vol. **50,** p. 544, January 23, 1903.

"Electrical Time-Service," by F. Hope-Jones, Associate.
Electrician, Vol. **50,** p. 669, February 13, 1903.

"Some Notes on the Electric Lighting of Rathmines," by G. F. Pilditch, Associate Member.
Electrical Engineer, Vol. **31,** Supplement of February 27, 1903.

"The Development of Electrical Energy Supplies," by M. Ruddle, Member.
Electrical Engineer, Vol. **31,** Supplement of March 20, 1903.

"Electrical Generating Stations of the Future," by A. W Whieldon, Member.
Electrical Engineer, Vol. **31,** p. 787, March 29, 1903.

"The Moving-Coil Ballistic Galvanometer," by W. G. Smith and M. Donegan.
Electrical Engineer, Vol. **31,** p. 830, June 5, 1903.

GLASGOW LOCAL SECTION.

"Generation of High-Voltage Electricity by Exhaust Steam," by Dr. M. Maclean, Member.
Electrician, Vol. **50,** p. 602, January 30, 1903.

"Electric Wiring Up-to-Date."
Electrical Review, Vol. **52,** p. 329, February 20, 1903.
Electrician, Vol. **50,** p. 1071, April 17, 1903.
Scottish Electrician, Vol. **3,** p. 37, February, 1903.
See also this volume, p. 834.

"THREE-PHASE HIGH-VOLTAGE ELECTRIC RAILWAYS, WITH SPECIAL REFERENCE TO THE VALTELLINA RAILWAY," by M. T. PICKSTONE, Member.
Scottish Electrician, Vol. **3**, p. 74, April, 1903.

"COMMUTATOR LOSSES," by W. B. HIRD, Member.
Scottish Electrician, Vol. **3**, p. 106, May, 1903.

MANCHESTER LOCAL SECTION.

"ELECTRICITY FROM REFUSE; THE CASE FOR THE MODERN DESTRUCTOR," by W. F. GOODRICH.
Electrical Engineer, Vol. **30**, Supplement of November 14, 1902.
Electrical Review, Vol. **51**, p. 851, November 21, 1902.
Electrical Times, Vol. **22**, p. 747, November 20, 1902.
Electrician, Vol. **50**, p. 221, November 28, 1902.

"ELECTRICAL HAULAGE ON CANALS," by Dr. E. W. MARCHANT, Associate Member.
Electrical Times, Vol. **22**, p. 936, December 26, 1902.
Electrician, Vol. **50**, p. 423, January 2, 1903.

"THE POSSIBLE DEVELOPMENTS OF ELECTRICAL DRIVING IN FACTORIES DUE TO THE SUPPLY OF ELECTRICITY AT CHEAP RATES BY LARGE POWER COMPANIES," by J. S. HIGHFIELD, Member.
Electrical Engineer, Vol. **31**, p. 300, February 27, 1903.
Electrical Review, Vol. **52**, p. 372, February 27, 1903.
Electrical Times, Vol. **23**, p. 293, February 19, 1903.
Electrician, Vol. **51**, p. 296, June 5, 1903.

"THE USE OF THE POTENTIOMETER IN THE MEASUREMENT OF TEMPERATURE OF FLUE AND FURNACE GASES," by W. A. PRICE.
Electrical Times, Vol. **23**, p. 525, March 26, 1903.
Electrician, Vol. **50**, p. 926, March 27, 1903.

NEWCASTLE LOCAL SECTION.

"SOME STATION NOTES," by C. TURNBULL, Associate Member.
Electrical Engineer, Vol. **31**, p. 193, Feb. 6, 1903.
Electrical Times, Vol. **23**, p. 213, February 5, 1903.

"NOTES ON MECHANICAL DETAILS OF ENCLOSED ARC LAMPS," by J. P. SLEIGH, Associate.
Electrical Engineer, Vol. **31**, Supplement of March 20, 1903.

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[D] signifies that the reference is to remarks made in a Discussion upon a paper, of which the general title or subject is quoted.

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[Glas. L.S.]	do.	do.	do.	of the Glasgow Local Section.
[Leeds L. S.]	do.	do.	do.	of the Leeds Local Section.
[Man. L.S.]	do.	do.	do.	of the Manchester Local Section.
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Note.—The lists of speakers in the Discussion upon any Paper are not quoted in the Index. They are, however, given in the Table of Contents at the beginning of the volume, and are readily found by ascertaining the page in the Journal from the entry in the Alphabetical Index, and then referring back to the corresponding portion of the Table of Contents, which is arranged serially in the order of the pages of the Journal.

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Barnes [C. W.]. The Electric Lighting of Merchant Vessels. 8vo. 105 pp. *London*, 1902

Bashforth [F.]. Historical Sketch of the Experimental Determination of the Resistance of the Air to the Motion of Projectiles. 8vo. 30 pp. *London*, 1903

Bond [W. G.]. Rating of Electricity Undertakings. 8vo. 31 pp. *London*, 1903

Bright [Charles, F.R.S.E.]. Imperial Telegraphic Communication and the "All British" Pacific Cable. 8vo. 32 pp. *London*, 1902

——— The Present Position of Wireless Telegraphy. 8vo. 7 pp. *London*, 1903

Clark [D. K.]. Mechanical Engineer's Pocket Book. 8vo. 692 pp. *London*, 1903

Ernst [Dr. Maurice]. Wireless Telegraphy and Telephony. 8vo. 32 pp. *London*, 1903

Fahie [J. J.]. Biographical Sketch of Mr. William Petrie. 8vo. 32 pp. *London*, 1903

Frick [John]. On Liquid Air and its Application. 8vo. 24 pp. *London*, 1901

Garcke [Emile]. Manual of Electrical Undertakings. Vol. vii. 8vo. 1,262 pp. *London*, 1902

Heyland [A.]. Asynchronmaschinen mit Kompensierung und Compoundierung in ihrer heutigen Ausführung. 4to. 22 pp. *Berlin*, 1903

——— Asynchronmaschinen mit Kurzgeschlossenem Kommutator, ohne in sich geschlossene lamellenverbindungen. 4to. 3 pp. *Berlin*, 1903

Humphrey [H. A.]. Producer-Gas and its Application to Industry. 8vo. 24 pp. *London*

——— Recent Progress in Large Gas Engines. 4to. 32 pp. *London*, 1902

***International Catalogue of Scientific Literature.** (C) **Physics.** Part II. 8vo. 207 pp. *London*, 1903

Italian Ministry of Public Works. Il Congresso di Londra del 1902 sulle Tramvie e Ferrovie Economiche. 4to. 118 pp. *Turin*, 1903

Jackson [A. H.]. The Electric Heat Furnace and its Industrial non-Electrolytic Uses. 8vo. 9 pp. *Melbourne*, 1902

Leaf [H. M.]. The Internal Wiring of Buildings. (2nd Ed.) 8vo. 230 pp. *London*, 1903

Madgen [W. L.]. Industrial Redistribution. 8vo. 86 pp. *London*, 1902

Munby [A. E., M.A.]. A Course of Simple Experiments in Magnetism and Electricity. 8vo. 90 pp. *London*, 1903

Munro [D. S.]. Safety Devices for Tramway Trolley Wires. 8vo. 14 pp. *London*, 1903

National Physical Laboratory. Report for year 1901. 4to. 54 pp. *London*, 1902

——— Report for year 1902. 4to. 51 pp. *London*, 1903

Nicholson [J.]. Telegraphic Vocabularies adapted to Telegraphic Signals. 8vo. 63 pp. *London*, 1903

Niethammer [Dr. F.]. Moderne Gesichtspunkte für den Entwurf Elektrischer Maschinen und Apparate. 8vo. 192 pp. *Munich*, 1903

Oerlikon, Ateliers de Construction. Première transmission d'énergie en Europe au moyen de courants triphasés à 30,000 volts. 4to. 26 pp. *Zürich*, 1903

——— 4to. 27 pp. *Zürich*, 1903

——— **Maschinenfabrik.** Die Elektrizitätswerke und Die Strassenbahn der Stadt Schaffhausen. 4to. 35 pp. *Zürich*, 1903

Owens [W. C.]. Telephone Lines. 8vo. 390 pp. *London*, 1903

Patent Office Library. Subject List of Works on Architecture and Building Construction. 8vo. 164 pp. *London*, 1903

——— Subject List of Works on General Science, Physics, Sound, Music, Light, Microscopy, and Philosophical Instruments. 8vo. 64 pp. *London*, 1903

Pollak-Virag Rapid Telegraph. 4to. 14 pp. *Berlin*, 1903

Radcliffe Library, Oxford. Catalogue of Books added during the year 1902. 4to. 26 pp. *Oxford*, 1903

Rosenberg [E.]. Electrical Engineering. Translated by W. W. H. Gee and C. Kinzbrunner. 8vo. 267 pp. *London*, 1903

Royal Observatory, Greenwich. Rates of Deck Watches (Oct. 35, 1902, to Feb. 14, 1903). 4to. 7 pp. *London*, 1903

——— Rates of Chronometers (July 5, 1902, to Jan. 24, 1903). 4to. 7 pp. *London*, 1903

Salomons [Sir D., Bart., M.A.]. Experiments with Vacuum Tubes. 8vo. 49 pp. *London*, 1903

Schaefer [C. W.]. The Milammeter. 8vo. 34 pp. *London*

——— A New Method of Localising Total Breaks in Submarine Cables. Improvements in the Localisation of Faults in Submarine Cables by Null-Method Bridge Measurement. 8vo. 34 pp. *London*

Semenza [G.]. La Trazione Elettrica sulle Ferrovie Italiane. 8vo. 24 pp. *Milan*, 1902

Walmsley [Dr. R. M.]. Electricity in the Service of Man.

Weightman [A. T.]. Cathodic Reduction. 8vo. 23 pp. *New York*, 1902

Williams [H.]. Mechanical Refrigeration. 8vo. 406 pp. *London*, 1903

Young [W.]. Spon's Architects' and Builders' Price Book. 8vo. 440 pp. *London*, 1903

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Argentine Year Book for 1902. 8vo. 504 pp. *Buenos Aires*, 1902
Presented by E. Danvers, Member.

Astronomer Royal. Report to the Board of Visitors of the Royal Observatory, Greenwich. June 7th, 1902. 4to. 25 pp. *London*, 1902

Atkinson [R. I.]. The "Via Eastern" Telegraph Social Code. 8vo. 320 pp. *London*, 1902

Behn-Eschenburg [Dr. H.]. Vierstufiger Drehstrommotor für 500, 750, 1,000, and 1,500 touren und Gleichstrommotor von 350, 1,600 touren der Maschinenfabrik Oerlikon. 8vo. 16 pp. *Zürich*, 1902
Presented by the Maschinenfabrik Oerlikon.

Birks [L.]. Electrical Distribution of Power (paper read before the Electrica Association of New South Wales). 8vo. 34 pp. *Sydney*, 1902

Borns [Dr. H.]. Die Elektrochemie im Jahre 1896, and annually to 1901. 8vo. *Berlin*

Bright [Charles, F.R.S.E.]. The Possibilities of Wireless Telegraphy (from the *Monthly Review*, Sept., 1902). 8vo. 14 pp. *London*, 1902

Cuénod [H.]. Distribution de la Force à Grande Distance par L'Électricité au Moyen du Courant Continu à Intensité Constante. 4to. 92 pp. *Paris*, 1900

Fahie [J. J.]. Staite and Petrie's Electric Light, 1846–1853 (reprinted from the *Electrical Engineer*, Aug. 29th, 1902). 44 pp. *London*, 1902

Grave [L. W. de]. Investigations into some Electric Accidents and the Means of Preventing them. La. 8vo. 20 pp. *Newcastle*, 1901

Hay [Professor A., B.Sc.]. The Principles of Alternate Current Working. 8vo. 388 pp. *London*, 1902

India Rubber, Gutta Percha, and Telegraph Works Co., Ltd. Log and Reports *re* New York–Canso Cable Expedition 1900, Waterville-Weston Cable Expedition 1901, ss. *Silvertown*, and relaying the Weston Shore end of the Waterville-Weston, 1901, Section, ss. *Buccaneer*. 8vo. 473 pp. *London*, 1902

Presented by Mr. R. Kaye Gray, Member.

Indian Government Telegraphs. Administration Report for 1901–1902. Fo. 10 pp. *Simla*, 1902

Presented by the Director-General of Telegraphs.

***International Catalogue of Scientific Literature.** (B) Mechanics. 8vo. 128 pp. (C) Physics, Part I. 8vo. 239 pp. (D) Chemistry, Part I. 8vo. 468 pp. (F) Meteorology. 8vo. 184 pp. *London*, 1902

International Engineering Congress, Glasgow, 1901. Report of the Proceedings and Abstracts of the Papers read. 8vo. 406 pp. *Glasgow*, 1902

——— **Proceedings of Section VI.** Mining and Metallurgy. La. 8vo. 306 pp. *Newcastle-on-Tyne*, 1902

Presented by the Institution of Mining Engineers.

Jona [E.]. Distanze Explosive nell'Aria, negli Olii ed altri Liquidi Isolanti. (Atti dell' Associazione Elettrotecnica. Italiania.) 4to. 32 pp. *Torino*, 1902

Konow [W.]. Fjernelsen af Støv og udund luft fra Fabriks Værksteds og Arbejdslokaler. 8vo. 95 pp. *Copenhagen*, 1902

Presented by the Teknisk Forenings Tidsskrift.

Mailloux [C. O.]. Notes on the Plotting of Speed Time Curves (from the Transactions of the American Institute of Electrical Engineers). 8vo. 111 pp. *New York*, 1902

Marriott [W.]. Hints to Meteorological Observers. 8vo. 60 pp.

Presented by the Meteorological Society. *London*, 1902

Maschinenfabrik Oerlikon. Die Elektrische Kraftzentrale St. Gilles der Lütticher Strassenbahn. 4to. 36 pp. *Zürich*, 1902

——— Die Elektrizität im Dienste der Textiliudustrie. 4to. 126 pp. *Zürich*, 1902

——— Electrical Drainage Installations (Vol. i.). 4to. 49 pp. *Zürich*, 1902

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——— Elektrische Kraftübertragungs und Beleuchtungsanlage von Evian und Thonon-les-Bains. 4to. 25 pp. *Zürich*, 1902

——— Elektrische Licht und Kraftverteilungsanlage Foligno. 4to. 34 pp. *Zürich*, 1902

——— Städtische Strassenbahn, Zürich. 4to. 54 pp. *Zürich*, 1902

Meares [J. W.]. Electric Traction. (Six lectures delivered in March, 1902, at the Civil Engineering College, Sibpur.) 8vo. 134 pp. *Calcutta*, 1902

Parr [G. D. A.]. Electrical Engineering Testing. 8vo. 474 pp. *London*, 1902

Patent Office.

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Patent Office Library. Guide to the Search Department of the Patent Office Library. 99 pp. *London*, 1901
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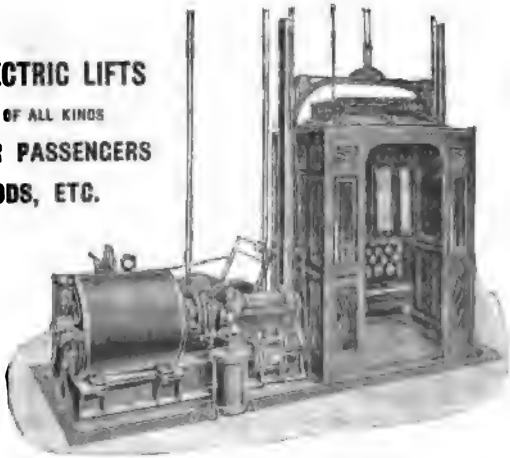

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